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Extended Desert Calculation Results With Comparisons to PRISCILLA Experimental Data and a Near-Ideal Calculation

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An extended calculation of the non-ideal airblast environment resulting from the PRISCILLA nuclear detonation has been completed. This calculation used the most recent, accepted interpretation of the experimentally determined thermal layer model.[1] The calculation included the effects of turbulence, surface roughness, and dust sweep-up in determining the near-surface blast environment. Full hydrodynamic definition of the precursor environment is now available from ground zero to a distance of over two kilometers. Information includes full spatial definition at selected times (about 25) and full-time, resolved waveforms at over 1,000 locations. the results of the calculation are compared with experimental data and show good to excellent agreement in all measured parameters.

An accompanying calculation without a thermal layer was also extended to over a two-kilometer range. This calculation served as the "ideal" case. The "ideal" calculation included the effects of surface roughness and turbulence but not an interaction with a thermal layer or dust sweep-up. Results of this calculation are used to quantify the differences specifically caused by thermal and dust interactions.

The excellent agreement between experiment and calculation demonstrates the degree of understanding of the physics involved in blast propagation over real surfaces. This understanding of the free-field environment is the necessary first step to predicting loads and response of vehicles or other targets subjected to such an environment.

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FOREWORD

This work was performed for the U.S. Army Research Laboratory (ARL) under Contract DAAL01-94-P-1217. The calculations were made using the latest version of the S-Cubed Hydrodynamic Advanced Research Code (SHARC). This code has been upgraded to include a version of a K-ε turbulence model, which has been modified by S-Cubed[2] for non-steady, compressible fluid flow. The turbulence model has a rough law of the wall boundary layer model[3] and a dust sweep-up model,[4] both of which were used for the desert calculation. The K-ε model and the rough law-of-the-wall were also used in the near-ideal calculation. It is the combination of high-order differencing, efficient computer algorithms, and realistic physical models that has made the agreement with experimental data possible.

We would like to acknowledge the efforts of Rich Lottero, Klaus Opalka, and Bud Raley of ARL for making this work possible, and John Keefer and Noel Ethridge of ARA for their guidance in matters of thermal layer development and experimental data interpretation.

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SECTION 1
BACKGROUND

This calculation is the product of over four decades of research into thermally-precursed airblast. It has been made possible by significant advances in numerical differencing techniques, physical modeling development, and computer hardware improvement. The importance of turbulence and a good boundary layer model were demonstrated during the DIAMOND ARC experiments in 1989[5].

The role of pre-shock dust has been debated for many years. The most recent calculations assume that pre-shock dust loading of the air is negligible. This is supported by several different types of observations. First, measurements of the temperature and sound speed as a function of height above desert surfaces[6] clearly show that the peak temperature occurs near the ground and decreases rapidly with height above the surface. If significant dust had been lofted, this dust would have absorbed incident radiation and caused heating of the air well above the ground. Second, photography from cameras located over two kILOMETERS from bus and truck targets[7] clearly show the buses and trucks until shock arrival. This means that the visible light, mean free-path is in excess of one kilometer and therefore, no significant absorption of radiated energy can occur in the three-meter depth of the observed dust height. Third, shock photography indicates that the precursor shock is linear and extends to very near the ground. If there were any significant enhancements of sound speed above the ground, the precursor shock would reflect the structure of the thermal layer with the front traveling faster in the highest sound speed region. This is further evidence that the thermal layer is hottest near the ground and cools rapidly with height. Fourth, arrival times measured by free-field gages and gages on structures[8] show that the signal arrival at ground level is earlier than at the three-foot elevation. Some gages on structures were only six inches above the surface. Even these gages show arrival after the ground-level gages. The shock is traveling faster at ground level than at six inches above the ground. The implication is that the hottest part of the thermal layer is less than six inches thick and that temperature decreases rapidly above that height. All of this points to negligible dust lofting prior to shock arrival.

One continuing subject for study is the observed fact that a precursor signal can and does travel subsonically at ranges beyond the 30-psi ideal overpressure range. This observation has not been fully utilized in this calculation and could lead to even better agreement with experiment at distances greater than one kilometer. The DIAMOND ARC arrival time data[5] indicate that the leading measured disturbance is traveling below the sound speed in the helium bag by about 30 % for all ranges beyond the 30 psi range. The implication is that sound speeds in the pre-shock thermal layer may be 30 to 50 percent greater than the measured signal velocity at ranges greater than 3500 feet for PRISCILLA. This phenomenon has been studied and reported in Reference 10 by Barthel at S-CUBED. Such an extended hot layer has not yet been used in a calculation.

SECTION 2
INITIAL CONDITIONS

The calculations described in Reference 9 were used as initial conditions for the extended calculations reported here. The "ideal" calculation was started from a time of two seconds and run to a time of four seconds.

The desert thermal layer calculation was restarted when the shock reached about 1,450 feet in ground range. The thermal layer temperature was increased to match a sensible upper bound of the experimentally-determined pre-shock thermal layer temperature and was run to a distance of 3,000 feet. The calculation indicated a shorter precursor prior to "main shock" arrival at the 3,000-foot range than was seen in the experiment, indicating that the thermal layer used in the calculation was not as hot as that which existed in the experiment. The thermal layer temperature for distances beyond 3,000 feet was re-evaluated, based on measurements interpreted from several nuclear events. The thermal layer was extended to a range of 4,300 feet. The calculation was restarted a second time at a distance of 2,500 feet and continued to four seconds and a distance of 6,000 feet. Figure 1 shows the three temperature/sound speed curves used for the three calculations. The results given in this report used the maximum of the three curves at any given distance.

Both calculations (ideal and precursed) used the S-CUBED K–ε turbulence model. This model is an extension of the usual K–ε model which uses a variable coefficient for formation and dissipation of turbulence, based on local conditions and the history of the flow. The S-CUBED modifications extend the K–ε model to compressible, non-steady flows. Both calculations used a law-of-the-wall for real surfaces in conjunction with the turbulence model. The ideal calculation used a smooth wall Clauser law-of-the-wall and the desert used a smooth wall Rubesin law-of-the-wall to represent the surface interaction.

The ideal calculation used a shock-following subgrid with 10-centemeter zones throughout most of the calculation. The precursor calculation used a similar shock following subgrid, but had 30-centemeter zones for most of the calculation duration.

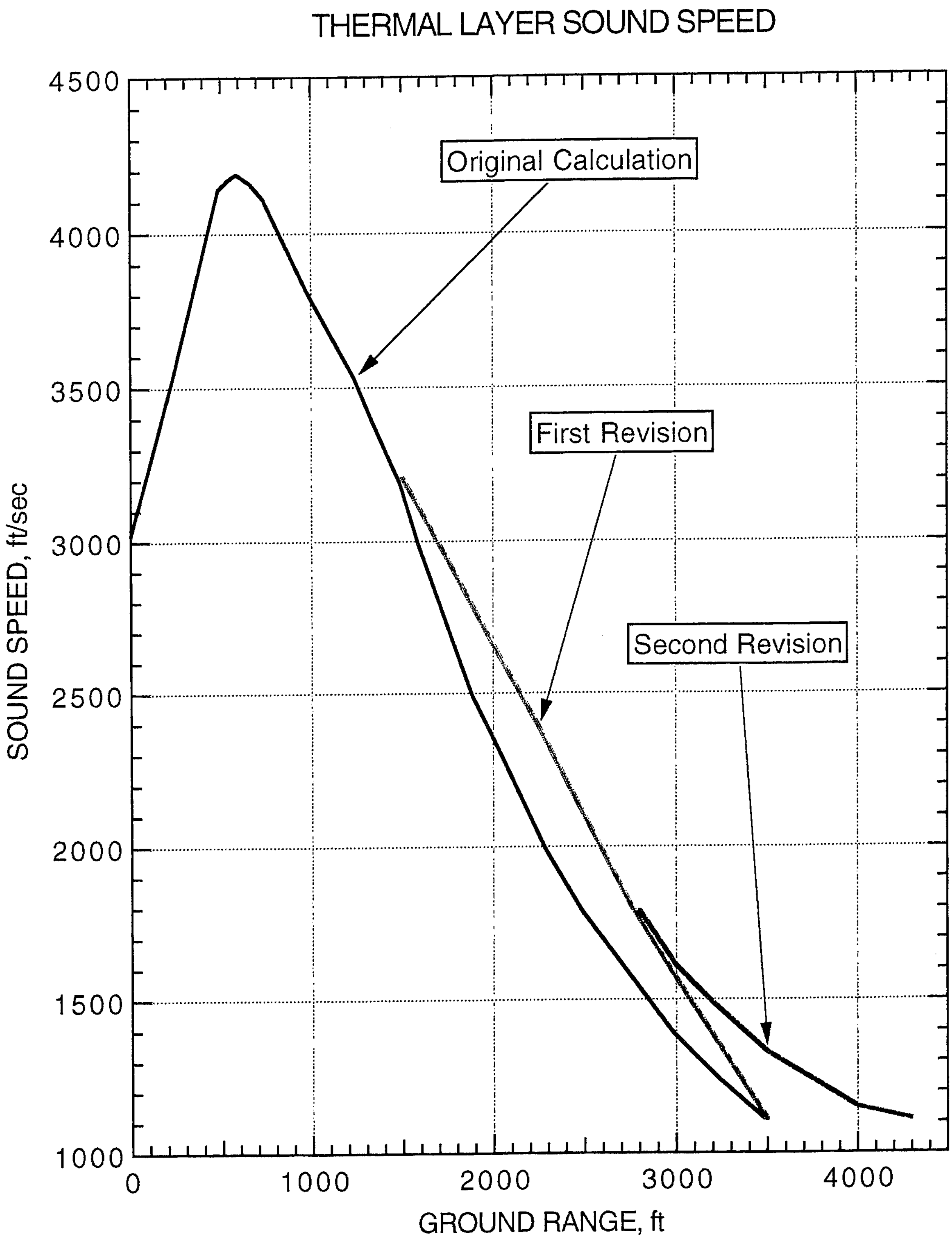

Figure 1. PRISCILLA sound speed vs. range.

SECTION 3
CALCULATED IDEAL RESULTS

The four-second problem time carried the shock front beyond the 6,000-foot range to an overpressure of just under 4 psi. The overpressures measured on PRISCILLA, beyond 4,000 feet, are in good agreement with the results of the ideal calculation. The overpressure positive phase was complete at the 5,000-foot range (about 5 psi) and the impulse agrees well with the experimental value at that distance. Because the positive phase was not complete beyond the 5,000-foot range, impulse comparisons could not be made in this region. Peak overpressures and waveforms for the ideal calculation for distances less than 3,000 feet were reported in Reference 9 and will not be repeated here, except as a reference for the desert calculation results.

A simple method was developed to remove the numerical overshoot observed on nearly all of the ideal waveforms. The overshoot peak was averaged with the first undershoot following the overshoot using the geometric mean. This method was developed under a previous contract and has been checked using results from several more complex interpolation methods. The geometric mean results have been found to be within acceptable error bounds, although perhaps a few percent high in some cases.

Summary plots of arrival time, overpressure, overpressure impulse, dynamic pressure, and dynamic pressure impulse are contained in Appendix A for the results of the ideal calculation. These results are compared to the results from the desert calculation and to experimental data from the PRISCILLA event. Waveform comparisons at a number of selected ranges are included in Appendix B. The waveforms are compared to the desert calculation results and to experimental waveforms where possible.

We have also included a number of parameter versus height plots at selected ground ranges. These extend from ground level to 40 feet above the ground. Comparisons are made with the results from the thermal layer calculation. These plots are included in Appendix C. Overpressure, arrival time, and impulse for the ideal calculation show very little variation with altitude. At large distances, beyond 4,000 feet, the rough surface has a small effect in reducing the near surface dynamic pressure.

SECTION 4
CALCULATED DESERT SURFACE RESULTS

A summary of the initial conditions is given in Section 2. Because the same thermal layer was used for this calculation as that reported in Reference 9, the results for distances less than 2,500 feet are the same as those of Reference 9 and will not be discussed here.

The calculation was carried to a time of four seconds and a distance of just over 6,000 feet. At the end of the calculation, the positive duration of the overpressure and dynamic pressure were complete for all ranges having overpressures greater than or equal to five psi.

During the calculation, we found that the station positions moved from the positions assigned as part of the initial conditions. We were able to trace this motion to the limitations of the 32-bit work station on which the desert calculation was made. During each rezone, the stations were assigned a new cell index position and this was converted back to a real distance. Because of the limited accuracy of 32-bit floating point arithmetic, many of the stations moved a small amount after each rezone. Several hundred rezones were completed during the progress of this calculation. Stations at larger ranges were effected more than those near ground zero.

The results reported in the summary plots of Appendix A have used the positions of the stations at the time of shock arrival. This problem does not effect the results of the ideal calculation because it was run on the Cray, a 64-bit machine. It also did not effect the vertical positions of the stations because few rezones occurred in the vertical direction. The vertical distances were small compared to the horizontal, and new zone indices were not calculated as often.

The dynamic pressures reported are the result of both air and dust contributions. The dust contribution has been assigned a "registry coefficient" of 0.5. The dust and air were treated as fluids and dynamic pressure was calculated as:

$$DP = 0.5 * rho * u * |u|, \qquad (1)$$

where rho is the total density (air plus dust) of the zone.

The arrival time curves on the first figure in Appendix A show that the precursor separates from the ideal at a distance of less than the height-of-burst and remains ahead of the ideal arrival throughout the two-kilometer ground range. The maximum separation between precursor arrival and ideal is just over 300 feet at a time of 0.6 seconds. The waveforms of Appendix B show that the precursor arrives before the ideal at ranges as small as 350 feet.

The summary plots of Appendix A show that the maximum overpressure in the desert thermal case is as little as one-third of the ideal overpressure. The overpressure at the precursor front may be more than an order of magnitude less than the peak pressure occurring later in the waveform. The overpressure impulse differs by less than ten percent from the ideal over the entire range of comparison.

The maximum dynamic pressure is, at some ranges, as much as a factor of three greater than the ideal. The dynamic pressure curves cross near 3,000 feet and the precursor peak dynamic pressure is less than that of the ideal for all greater ranges. The dynamic pressure impulse exceeds the ideal by as much as a factor of eight between ground ranges of 2,000 and 3,500 feet, then falls below the ideal values at greater ranges.

The waveforms of Appendix B show the details of many of the features described above. At a range of 2,500 feet, the ground-level overpressure waveform has a rounded front, with the peak overpressure near the front. Only a single peak is evident. The peak overpressure is about one-third of that for the ideal calculation. Overpressures at three and ten feet are very close to those at ground level. The dynamic pressure waveform shows that the maximum pressure occurs in a secondary peak some 300 milliseconds behind the precursor wave. The peak is about two and one-half times the ideal peak.

At a range of 3,000 feet, the overpressure waveforms are similar but the non-ideal peak is about half that of the ideal. The increase relative to the ideal is a sign of the precursor front slowing and decreasing in extent. The dynamic pressure waveform at this range shows two major rounded peaks, with the second occurring about 150 milliseconds after arrival. The peak is about twice that of the ideal. The decrease in separation time of the two peaks beyond 2,500 feet is a further indication of the beginnings of precursor clean-up.

By 3,500 feet, the calculation shows a rounded front, an inflection, and a sharp rise to a peak overpressure which is about 75 percent that of the ideal. The sharp rise to the second peak is an indication of precursor clean-up. The dynamic pressure waveform shows multiple peaks and a slow rise after first arrival. The peak dynamic pressure is comparable to the ideal peak. The decay after the peak is reached is much slower than in the ideal case and leads to a dynamic pressure impulse of about three times the ideal.

At a range of 4,000 feet, the overpressure waveform is nearly ideal. The major difference between precursed and ideal at this range is that the peak overpressure is a few percent lower than the ideal. The dynamic pressure waveform shows that the precursed waveform falls below the ideal at all times, thus causing a lower dynamic pressure impulse.

For ranges beyond 4,000 feet, the non-ideal waveforms are very close to the ideal but the arrival times are somewhat smaller and the peaks remain a few percent lower than ideal.

Appendix C contains comparisons of various parameters as a function of height at selected ground ranges. The plots cover the variation with altitude from ground level to 40 feet above the ground. At the 2,100-foot ground range, the peak precursor overpressure is about one-third that of the ideal with the near ground-level pressure as much as 50 percent greater than that above 10 feet in altitude. The ideal does not vary with altitude to less than one percent.

At 2,300 feet, some variation in peak overpressure is seen in the lower 10 feet, but the variations are less than 30 percent in the precursor case. In general, the precursed maximum overpressures are about one-third those of the ideal. The ideal shows no variation with altitude.

The comparison at 2,550 feet shows the precursor pressures to be less than half those of the ideal case. Variations with altitude are less than ten percent for the precursor and less than one percent for the ideal. This trend continues through the 2,950-foot ground range.

The temperature and sound speed in the thermal layer decrease rapidly beyond a range of 3,000 ft. This marks the clean-up phase of precursor propagation. The variation with height at 3,250 and 3,650 shows dramatic changes as the layer cools. At

3,250 feet the peak overpressure at 40 feet above the surface is about 30 percent greater than near the surface, but is still about 75 percent of the ideal. The ideal remains unchanged with height. By 3,650 feet, the overpressure above 20 feet differs from the ideal by less than 10 percent, while near ground level the overpressures are about 80 percent of ideal.

The thermal layer terminated at the 4,300-foot range; no pre-shock heating was present beyond this range. The variations with height beyond the end of the thermal layer are caused by residual differences in energy distribution in the shock and transient flows which are attempting to equilibrate along the shock front. Variations in height are small, of the order of two percent, and the differences between precursed and ideal are less than ten percent.

The arrival time as a function of height plots show no surprises. The curves are very smooth and show that the arrival at ground level is earlier than at any other height. This is in agreement with observed arrival times on structures from the PRISCILLA event. The precursor arrival times are earlier than the ideal for all ground ranges. Beyond the 4,300-foot range, the arrival time does not change with height.

The dynamic pressure plots of Appendix C show that the dynamic pressure nearest ground level is about a factor of two higher than at an elevation of three feet at the 2,100-foot ground range. This characteristic decays rapidly as the boundary layer grows behind the precursor front. By 2,500 feet, the maximum dynamic pressure occurs three to six feet above the ground. For all ground ranges less than about 3,200 feet, the precursed dynamic pressure exceeds that of the ideal near ground level. At 2,950 feet, the dynamic pressure near ground level is more than twice the ideal but falls below the ideal above 35 feet from the surface.

As with the overpressure, several oscillations are present in dynamic pressure as the precursor cleans up. Apparently, energy is exchanged between dynamic pressure and overpressure as the shock front adjusts to the absence of a thermal layer.

The most dramatic effect is seen in the dynamic pressure impulse. At a range of 2,100 feet, the near-surface dynamic pressure impulse from the precursor calculation exceeds the ideal by more than an order of magnitude, while at the three-foot elevation, the ideal is exceeded by about a factor of five. The impulse remains greater than the ideal for all heights. Some effect of the boundary layer can be seen in the reduction of dynamic pressure impulse for the ideal case also.

The effect of the boundary layer is evident in the 2,300-foot plot. The impulse for the precursed calculation changes from being greatest at ground level to being reduced such that the maximum occurs near the three-foot height. The ideal impulse is also reduced near ground level.

The maximum impulse of the precursor is greater than the ideal at all heights, but approaches the ideal near the 40-foot height throughout the clean-up phase, to a distance of nearly 4,000 feet. The impulse drops sharply beyond 4,000 feet and falls below the ideal for the remainder of the calculated range.

SECTION 5
COMPARISONS OF CALCULATIONS WITH EXPERIMENTAL DATA

The summary plots of Appendix A contain comparisons of calculations with nearly all available data from the PRISCILLA event.

The arrival time curve shows excellent agreement with the majority of the data. Some data have been questioned (Keefer private communication) because of the type of instrumentation used. In general, the desert calculation shows good agreement with the measured data and its wave front always arrives earlier at any given range than does that of the ideal case. The data indicates a faster propagation at ranges beyond 3,500 feet than was calculated. This is one of many indications that a significant thermal layer existed well beyond the 4,000-foot range in the PRISCILLA test.

The overpressure summary plot includes experimental data from ground level, three-foot and ten-foot heights. The three- and ten-foot elevation data agree better with the ideal overpressures than with the precursor values. The calculated overpressures are for ground level only. Two overpressures are plotted for each calculation: the first peak and the maximum. The only range for which these curves differ in the ideal case is during double and complex Mach reflection. This limited region extends from about 600 to 1,400 feet. For the precursor calculation, the peak overpressure falls below the ideal almost immediately. As the precursor forms and generates a double peaked waveform, the two curves diverge. At a range of 350 feet, only one peak is present, but by 500 feet a weak shock having a peak of about 10 percent [1] of the maximum leads the so-called "main wave". The precursed overpressure peaks fall below those of the ideal to a range of just over 4,000 feet, the end of the thermal layer. The first peak may be as little as 10% of the maximum overpressure at a given range.

The calculated precursor overpressure is in good agreement with all of the experimental data. It should be noted that the overpressure reaches a relative minimum at a range of just over 2,500 feet, then rises to a relative maximum at about 4,000 feet. This maximum is slightly higher than the ideal at this range. The peak then falls back to the ideal level for the remainder of the calculated ranges. This behavior is in agreement with the experimental data from several nuclear shots, including PRISCILLA.

The increase in overpressure as a function of ground range, beyond the 2,500-foot range, has been observed experimentally and is now confirmed by calculation. The rise and fall of the overpressure with range leads to a triple valued function for the range of a given overpressure; *e.g.*, there are three ranges at which 8 psi occurs. The calculation indicates 2,200, 3,200, and 4,100 feet all had a peak overpressure of 8 psi. This triple valued function is the cause of the non-ideal height-of-burst curves having loops and multiple values as a function of ground range and height of burst. These characteristics are real, calculable, and we believe that we now understand them.

The overpressure impulse data have considerably more scatter than the peaks. The calculations fall near the high side of the data. The causes for this scatter can be seen in the waveforms of Appendix B. Some waveforms fall below ambient at a relatively early time after shock arrival, while others do not return to ambient for an extended period. Such scatter is an indication of the difficulty of making measurements in the nuclear environment and the variety of waveforms measured at the same ground

[1] The agreement of the computation with the BRL waveform at 1650 feet is apparently fortuitous. The timing on the BRL waveform is now believed to be in error; the BRL waveform should be expanded so that the maximum peak coincides with that on the SRI peak. The BRL self-recording gages used in PRISCILLA did not have a timing-mark generator.

range. The waveforms depend on the integrated history of the interaction of the shock with the thermal layer, and surface irregularities contribute significantly to variations in this history.

The peak dynamic pressure summary plot shows that the peak measured values differ, in general, by about a factor of two to three from the ideal. The data are above the ideal for ground ranges between 1,200 feet and 3,200 feet. The calculated precursor results show this range of variation and agree with the range at which the dynamic pressure falls below the ideal.

The dynamic pressure impulse data, taken three feet above the surface, are in good agreement with the precursor calculated results. When viewed as in the sixth figure of Appendix A, the data fall onto two lines. The first line is very near the ideal, while the second closely follows the precursor calculation. The data and the calculation indicate that for some ranges the dynamic pressure impulse may exceed the ideal by more than an order of magnitude.

The waveforms of Appendix B include all available desert line waveforms. No effort has been made to edit, delete, or emphasize any particular waveform or comparison. Many of the gages did not have associated arrival times, but times were given as relative to first signal arrival. We have shifted all desert waveforms so that the first signal arrives at the time of the calculated precursor waveform. Because the current calculation differs from that of Reference 9, only at distances greater than 1,450 feet, the discussion of waveform comparisons will be limited to those beyond the 1,450 foot range.

The calculated waveforms of Appendix B represent the mean flow parameters at the positions given. The calculations include the turbulent contribution as a separate parameter. Waveforms using a combination of the mean parameters and the turbulent contribution can be reconstructed from the calculations. This reconstruction includes a full frequency distribution of the Kolmogorov spectrum. The resulting waveforms must then be low-pass filtered to the characteristics of a given gage before comparisons can be made; this has not been done here. The calculated waveforms are therefore somewhat smoother than the data because of the lack of the turbulent component. The turbulence will add oscillations on the waveforms, but impulse values will not be changed.

At 1,650 feet, the agreement between the calculated precursor and the BRL measured overpressure waveforms is excellent. The SRI gage shows greater separation between first and second peaks and a somewhat higher second peak.

At 2,000 feet, the two SRI gages show high, spiking secondary peaks which are as high as those measured at the 1,650-foot range and above the ideal at this range. The calculation shows excellent agreement with the rise and shape of the first peak and agrees with the timing between first and second peaks, but falls well below the second peak pressure. This comparison must be weighed against the measurements taken before and after this ground range.

Some 250 feet further, at 2,250 feet, the BRL waveform indicates no such secondary spike. The calculated precursor waveform is again in excellent agreement with the data.

By 2,500 feet, the second peak is no longer apparent in the waveform. The SRI and BRL gages are in agreement, and the calculated waveform follows the same pattern.

At 3,000 feet, the BRL, SRI, and calculated precursor waveforms are essentially overlays. The two data waveforms show a small spike near 1.25 seconds. The spike indicates the formation of a secondary shock as precursor clean-up begins. This is not apparent in the calculation.

The clean-up continues, as seen at the 3,500-foot range. The calculation has a shorter, rounded front and a higher second peak than the experimental waveform. This is a further indication that the thermal layer used in this calculation is cooler than existed in the experiment at this range. The experimental waveform falls more quickly after the peak, but this should be compared with the waveform measured just three feet above the ground. Here, the SRI data merges with the calculated waveforms after about 1.7 seconds.

The premature clean-up of the calculation is further demonstrated in the waveforms compared at 4,000 feet. The experiment shows a separation of about 30 ms between the first and second peaks, but the calculation has a single, rapid rise indicates nearly complete clean-up at this range.

SECTION 6
CONCLUSIONS

The results of the "ideal" calculation serve as a benchmark for the definition of the entire airblast flowfield over a realistic surface. This calculation is being and will be used to compare and quantify the effects of dust and thermal layers. The zone size remained at 10 centimeters in the shock following sub-grid to a distance of over 1.2 kilometers. The zone size in the subgrid was then gradually increased to a maximum of 30 centimeters as the shock approached 2 kilometers. The resolution is adequate for this calculation to be considered state-of-the-art.

The desert calculation required some compromise on resolution. The moving subgrid contained zones with dimensions of 30 centimeters throughout the calculation. This compromise was necessary in order to assure completion of the calculation within cost constraints. A desert thermal layer calculation with 10-centimeter resolution at the PRISCILLA scale is still a very desirable goal. This calculation has sufficient resolution to answer many of the questions about thermal layer temperature distribution and the role of dust in the overall flowfield. A higher resolution calculation will require careful reconsideration of the temperature distribution in the thermal layer, the extent of the high sound-speed region, and the consequences of temperature gradients on precursor cleanup.

The desert precursor calculation results, presented here, show the best agreement with experimental data of any calculation by any organization done to date. This comparison includes arrival times, overpressures, dynamic pressures, impulses, and waveform details. We now have defined the flowfield for the PRISCILLA event in sufficient detail to provide high quality environment descriptions, above 25 psi but with less fidelity at lower pressures.

The results of this calculation are being transferred to magnetic media and will be available for further detailed analysis in the future. Some questions about the role of dust versus air in the measurement of dynamic pressure have already been addressed during the comparisons between calculational results and experimental data. The growth of a boundary layer and the interaction of the precursor with the boundary layer can be more fully examined. The role of turbulence in dust lofting and dust distribution behind the precursor is yet to be addressed in detail. Many insights into these associated phenomena and some answers are now available, but further analysis is required to exploit fully this pair of computations.

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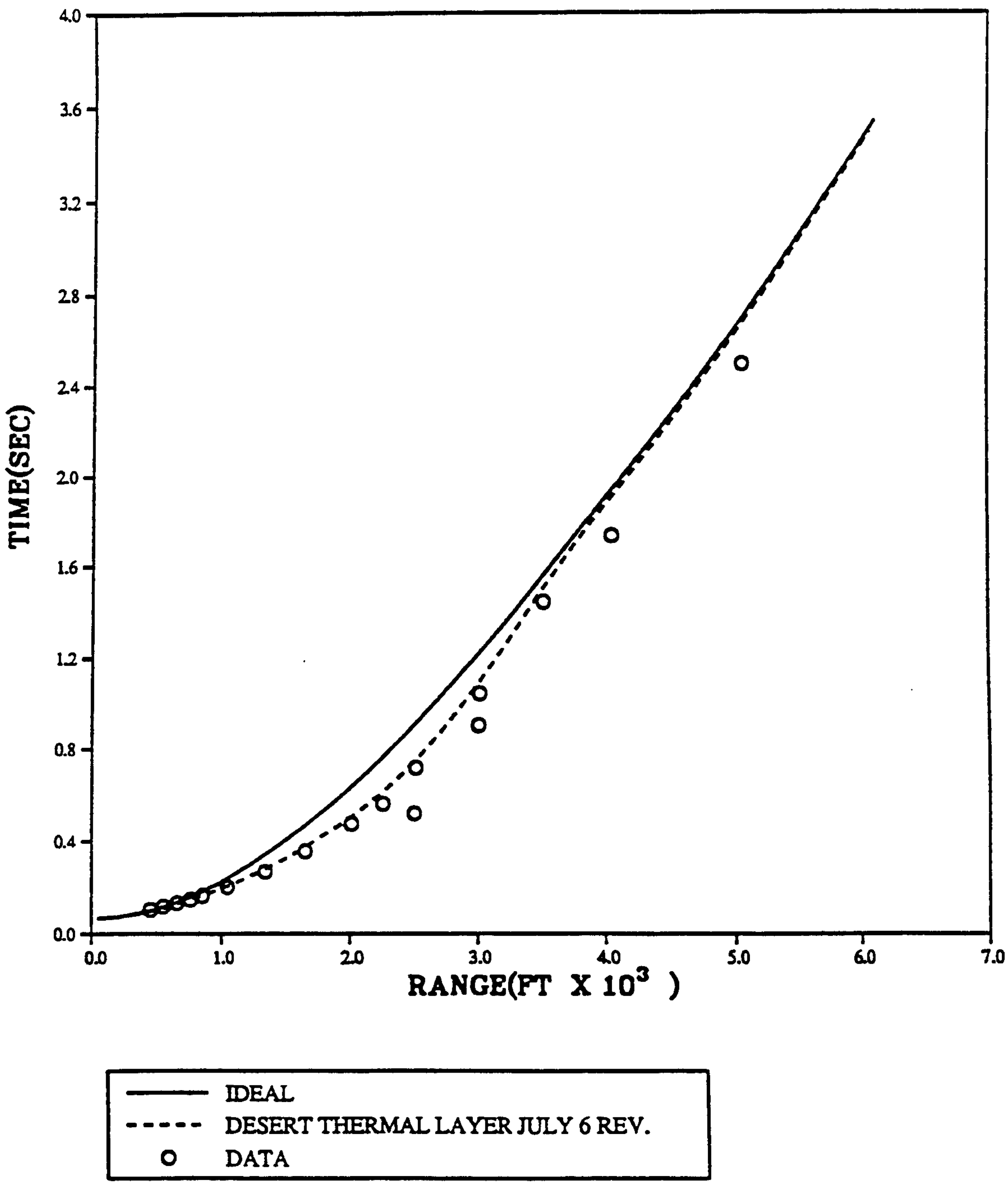
APPENDIX A
PARAMETER SUMMARY PLOTS

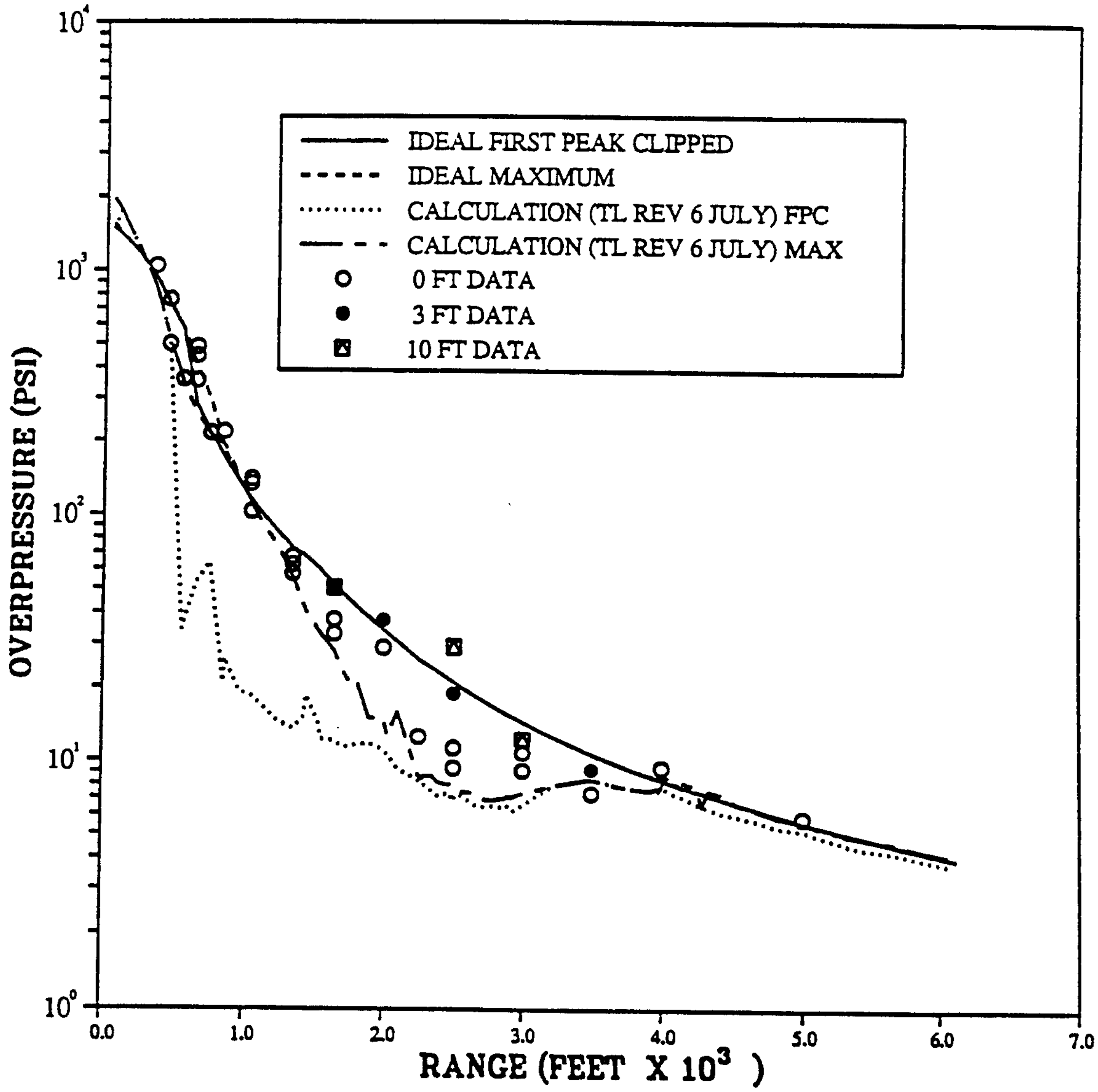
This Appendix contains summary plots of hydrodynamic parameters as a function of ground range. Each plot contains the results of the ideal calculation, the desert calculation, and experimental data. No dynamic pressure measurements were made at ground level. All the experimental dynamic pressure data were taken at least three feet above the surface. Many of the dynamic pressures from the experiment were derived from stagnation pressure measurements at a 3-foot elevation and the overpressure measurements at ground level. The results from the PRISCILLA calculation show that the overpressure varies between ground level and three feet in the region of strong precursor and the assumption of equal overpressures may be in error by 10% or so.

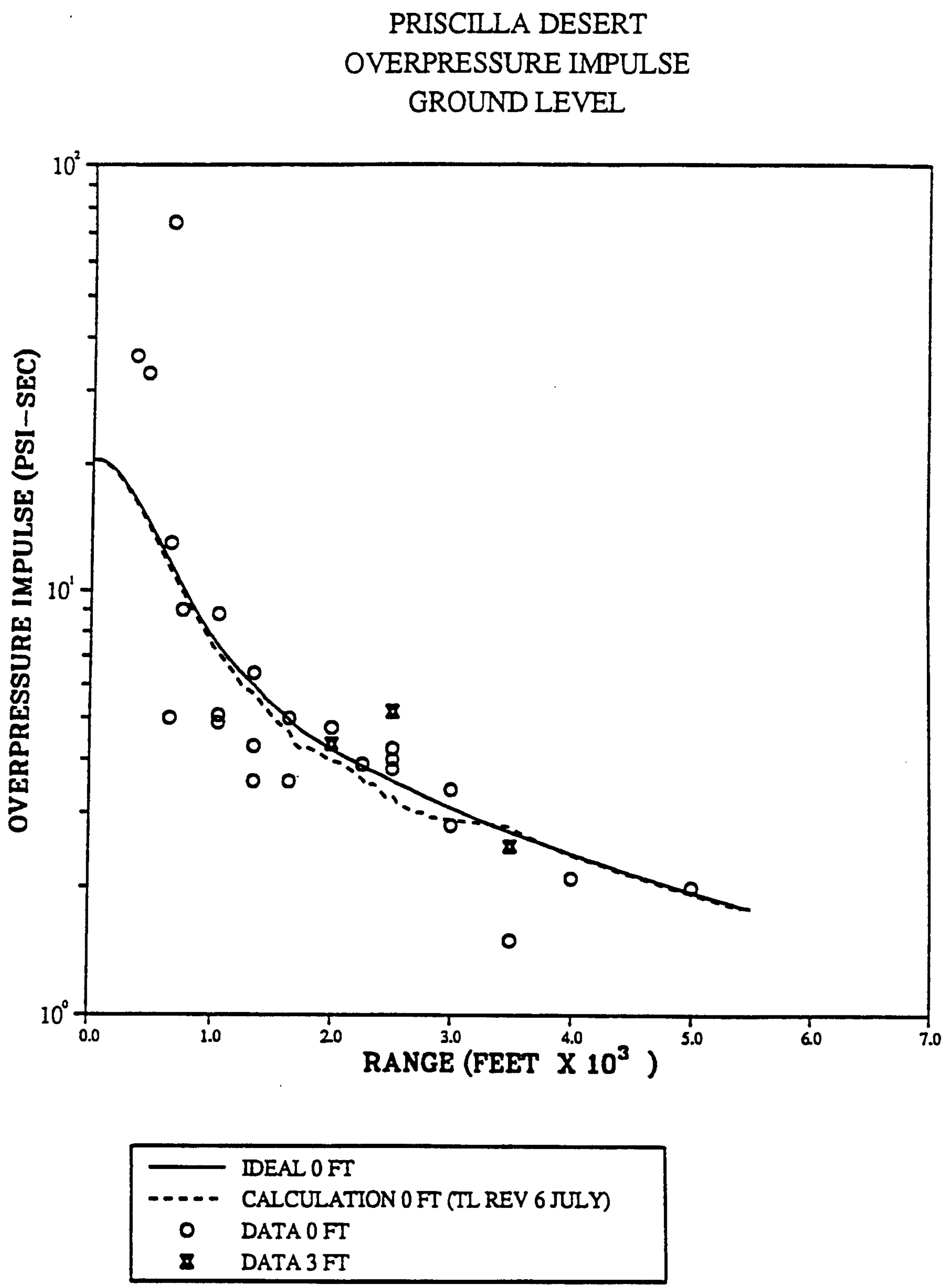
All measured dynamic pressures are taken without regard to the type of gage or its dust registry coefficient. The calculated dynamic pressures include the dust dynamic pressure contribution. In the plots from these calculations, the dust is treated as a fluid and has a registry coefficient of 0.5.

PRISCILLA
ARRIVAL TIME AT GROUND LEVEL



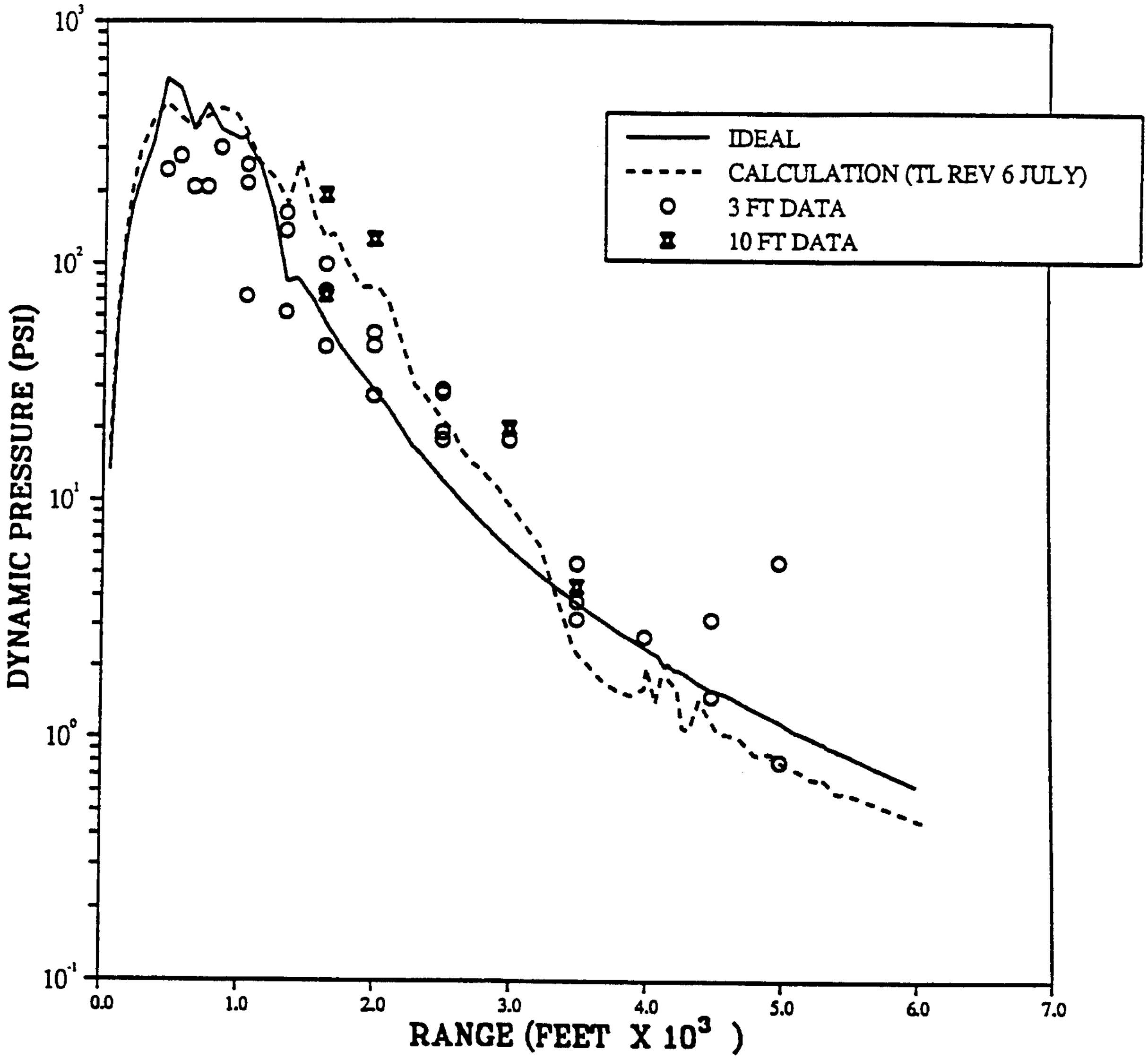
PRISCILLA DESERT
OVERPRESSURE AT GROUND LEVEL



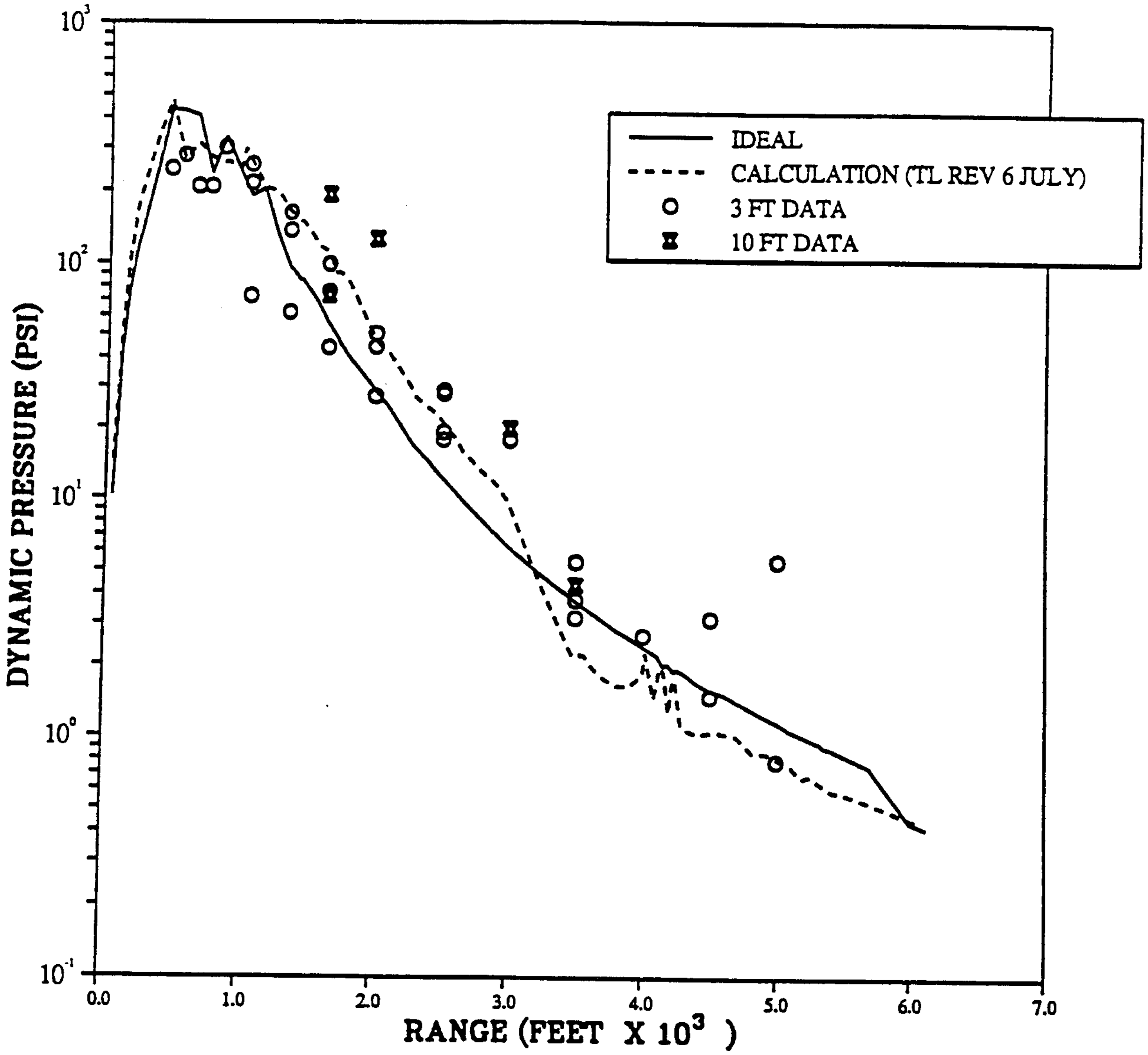


PRISCILLA DESERT
OVERPRESSURE IMPULSE
GROUND LEVEL
10^2
10^1
10^0
OVERPRESSURE IMPULSE (PSI-SEC)
0.0
1.0
2.0
3.0
4.0
5.0
6.0
7.0
RANGE (FEET X 10^3)
IDEAL 0 FT
CALCULATION 0 FT (TL REV 6 JULY)
DATA 0 FT
DATA 3 FT

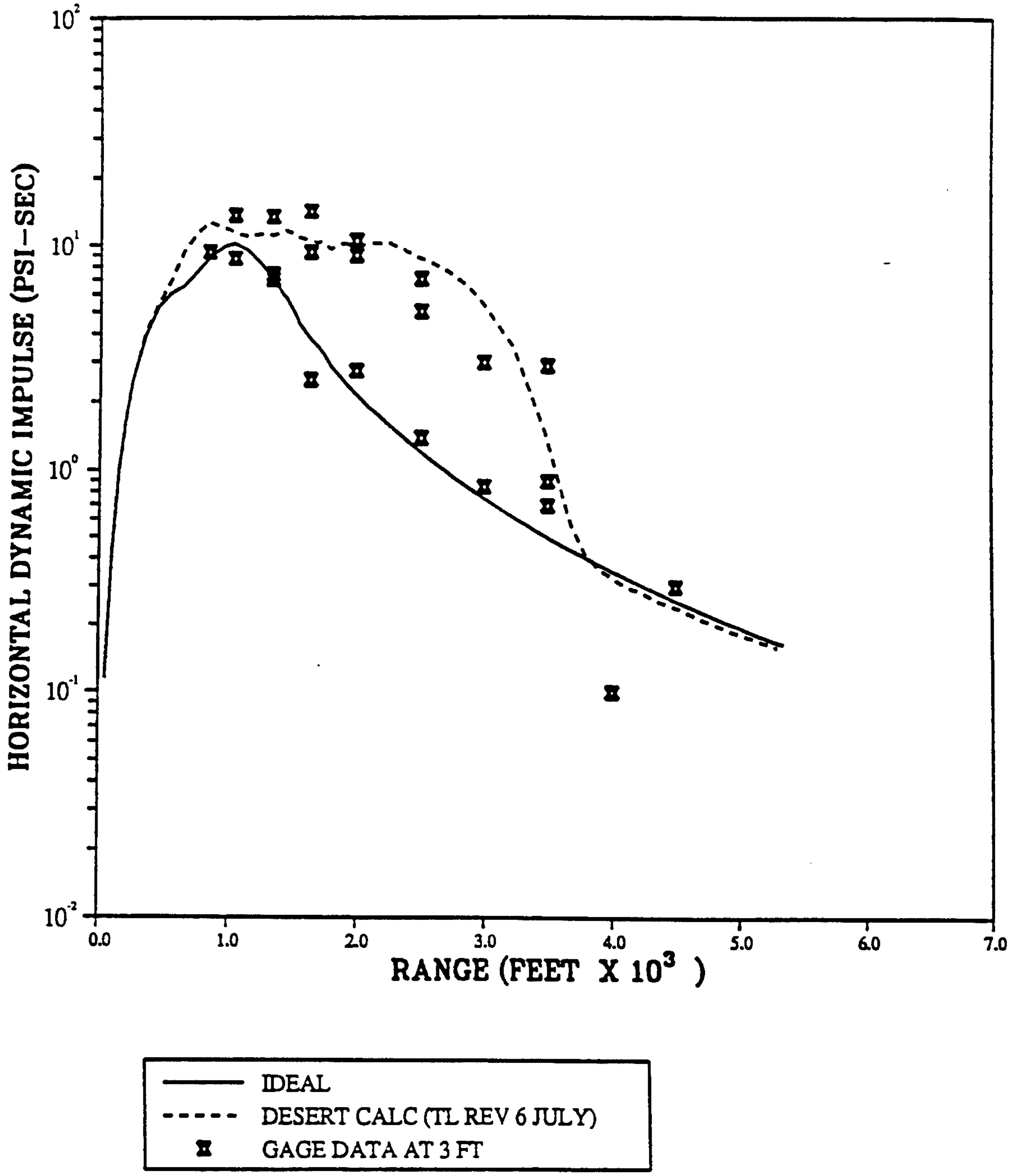
PRISCILLA DESERT
HORIZONTAL DYNAMIC PRESSURE PEAKS
91.44 CM LEVEL (3 FEET)

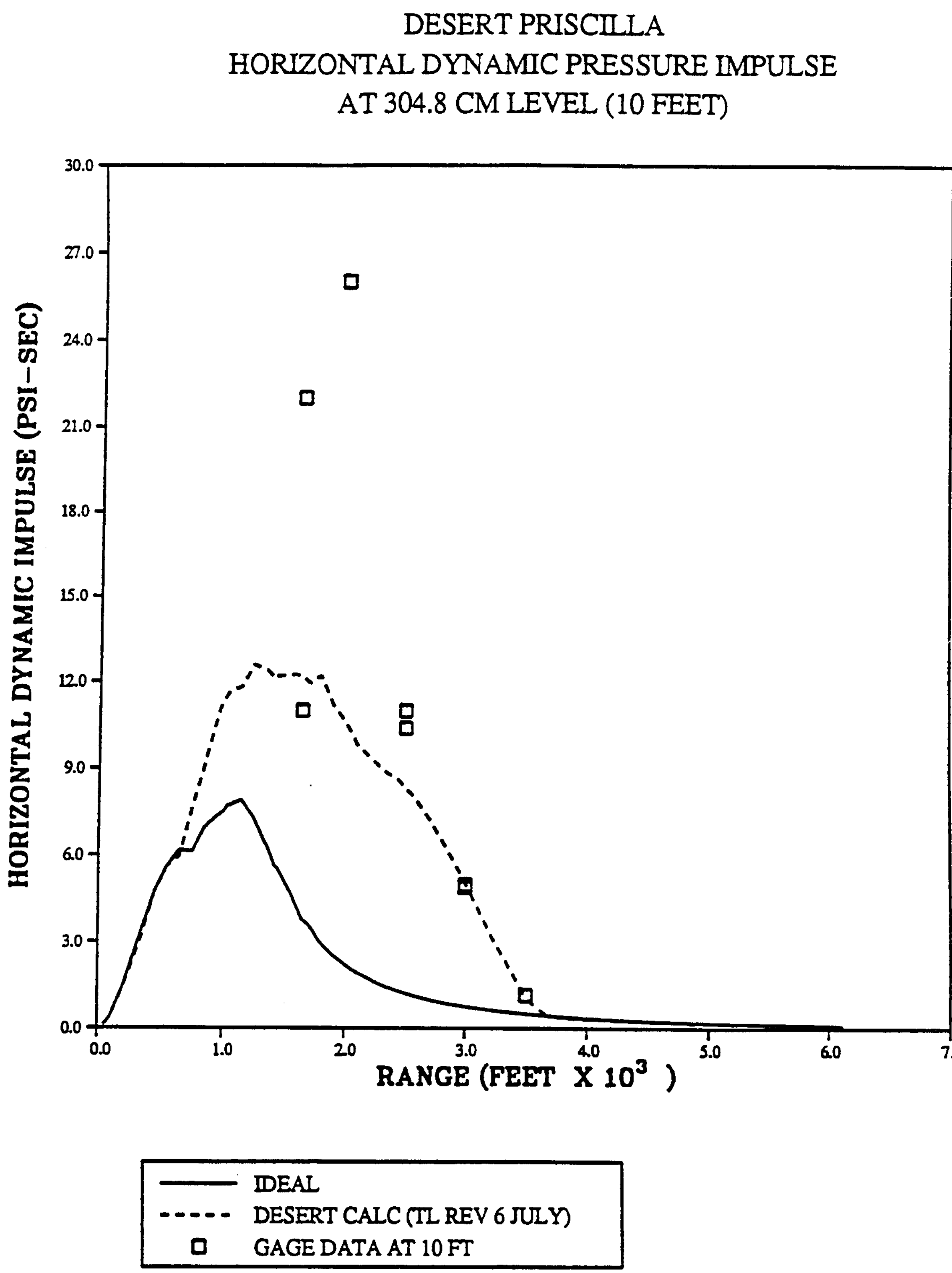


PRISCILLA DESERT
HORIZONTAL DYNAMIC PRESSURE PEAKS
304.8 CM LEVEL (10 FEET)



DESERT PRISCILLA
HORIZONTAL DYNAMIC PRESSURE IMPULSE
AT 91.44 CM LEVEL (3 FEET)



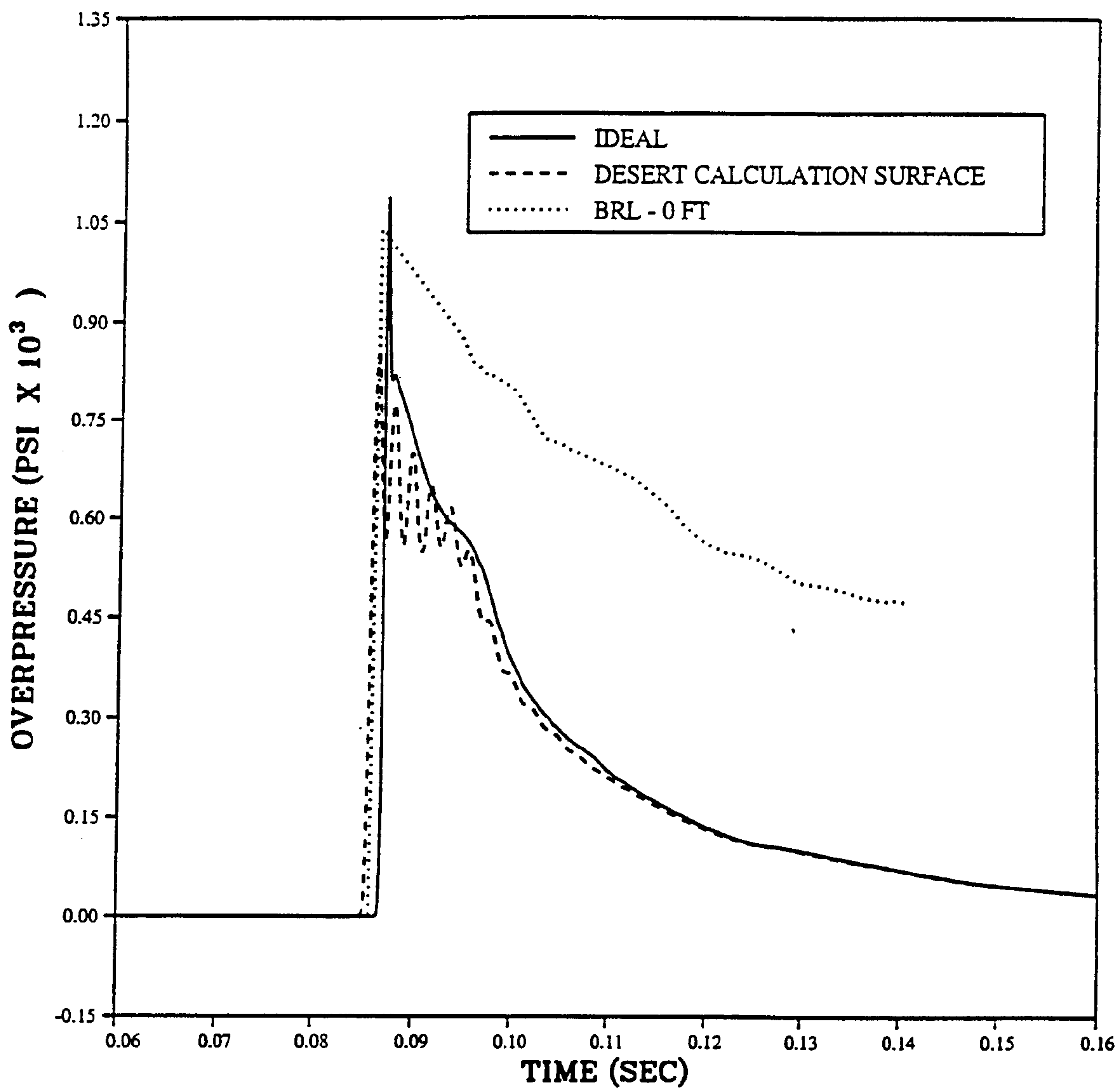

DESERT PRISCILLA
HORIZONTAL DYNAMIC PRESSURE IMPULSE
AT 304.8 CM LEVEL (10 FEET)
HORIZONTAL DYNAMIC IMPULSE (PSI-SEC)
30.0
27.0
24.0
21.0
18.0
15.0
12.0
9.0
6.0
3.0
0.0
0.0
1.0
2.0
3.0
4.0
5.0
6.0
7.0
RANGE (FEET X 10^3)
IDEAL
DESERT CALC (TL REV 6 JULY)
GAGE DATA AT 10 FT

APPENDIX B
WAVEFORM COMPARISONS

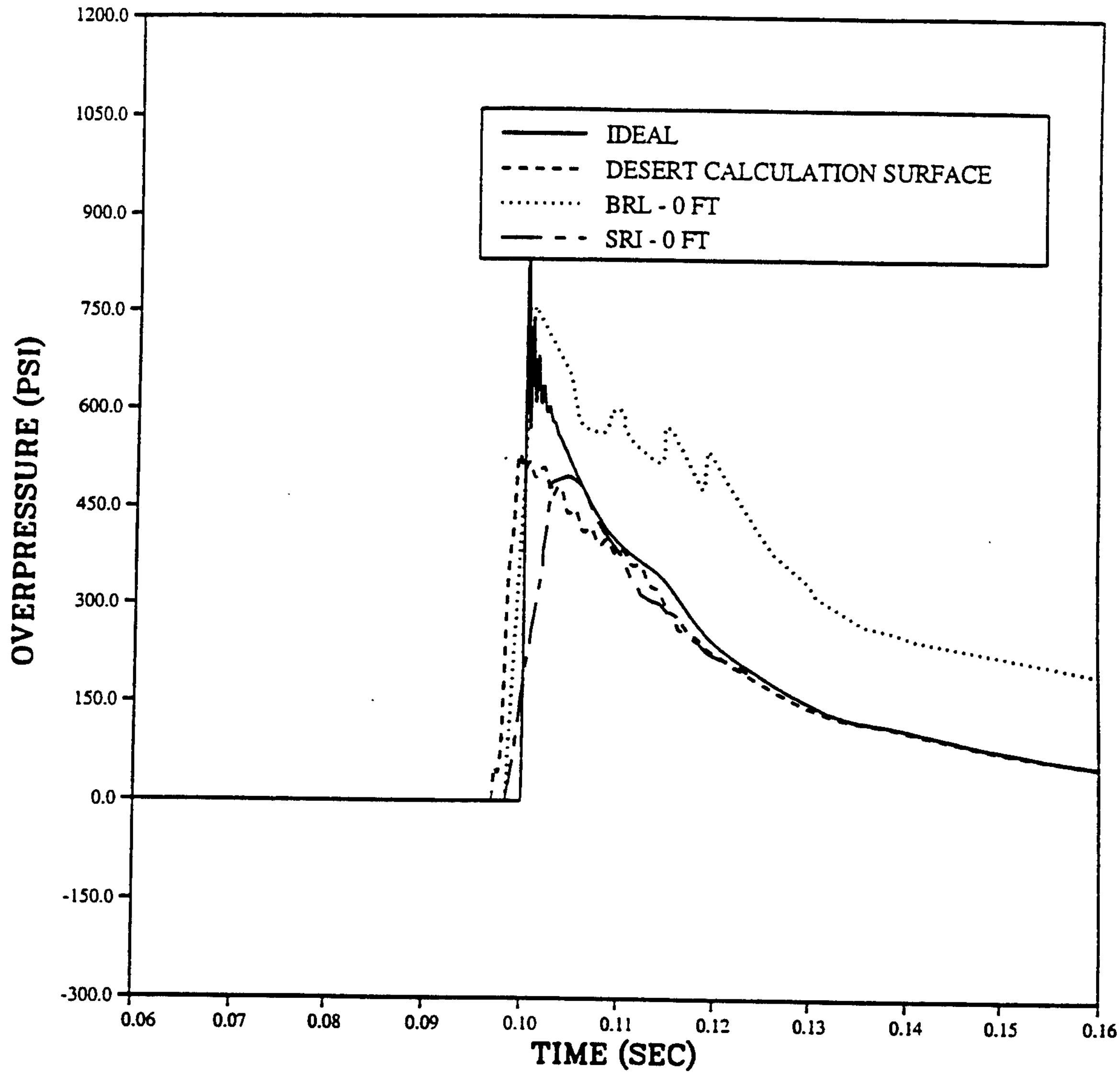
This Appendix contains waveform comparisons of overpressure, dynamic pressure, and their impulses. Each plot contains the ideal waveform, the calculated precursor waveform, and at least one measured waveform at the corresponding distance. Arrival time of the measured waveform has been shifted to agree with the precursor calculation.

More information is available. The dust density as a function of time has been calculated and saved. It is possible to determine the calculated air and dust dynamic pressures independently. Any desired dust registry coefficient or a functional form of the dust registry coefficient may be used. Mach number of the flow as a function of time is also available at any of the station positions. Full descriptions of the turbulence environment are also available at each station, including the turbulent energy and the rate of turbulence dissipation.

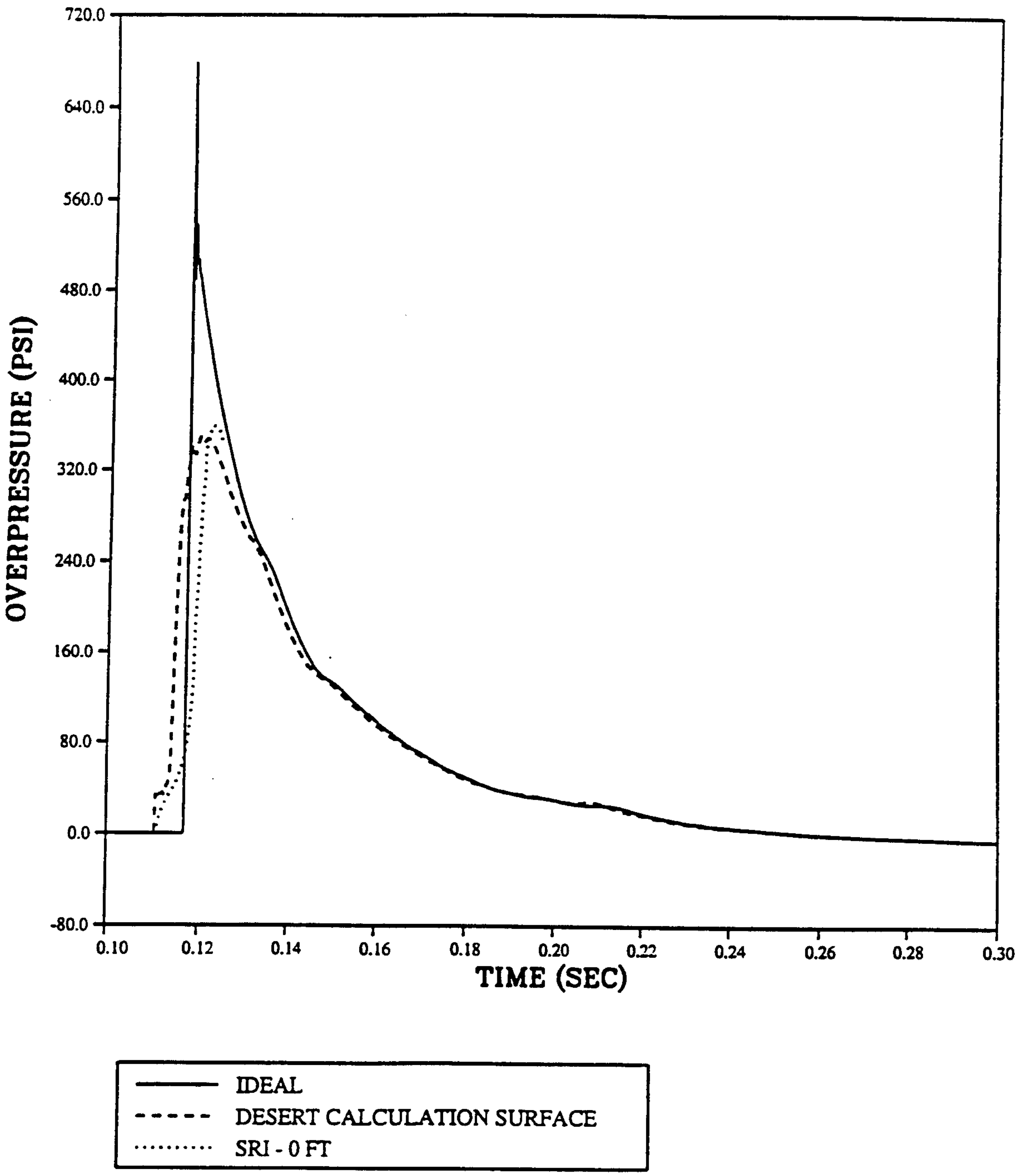
PRISCILLA
CALCULATION - DATA COMPARISONS
OVERPRESSURE AT 350 FEET (107 M)



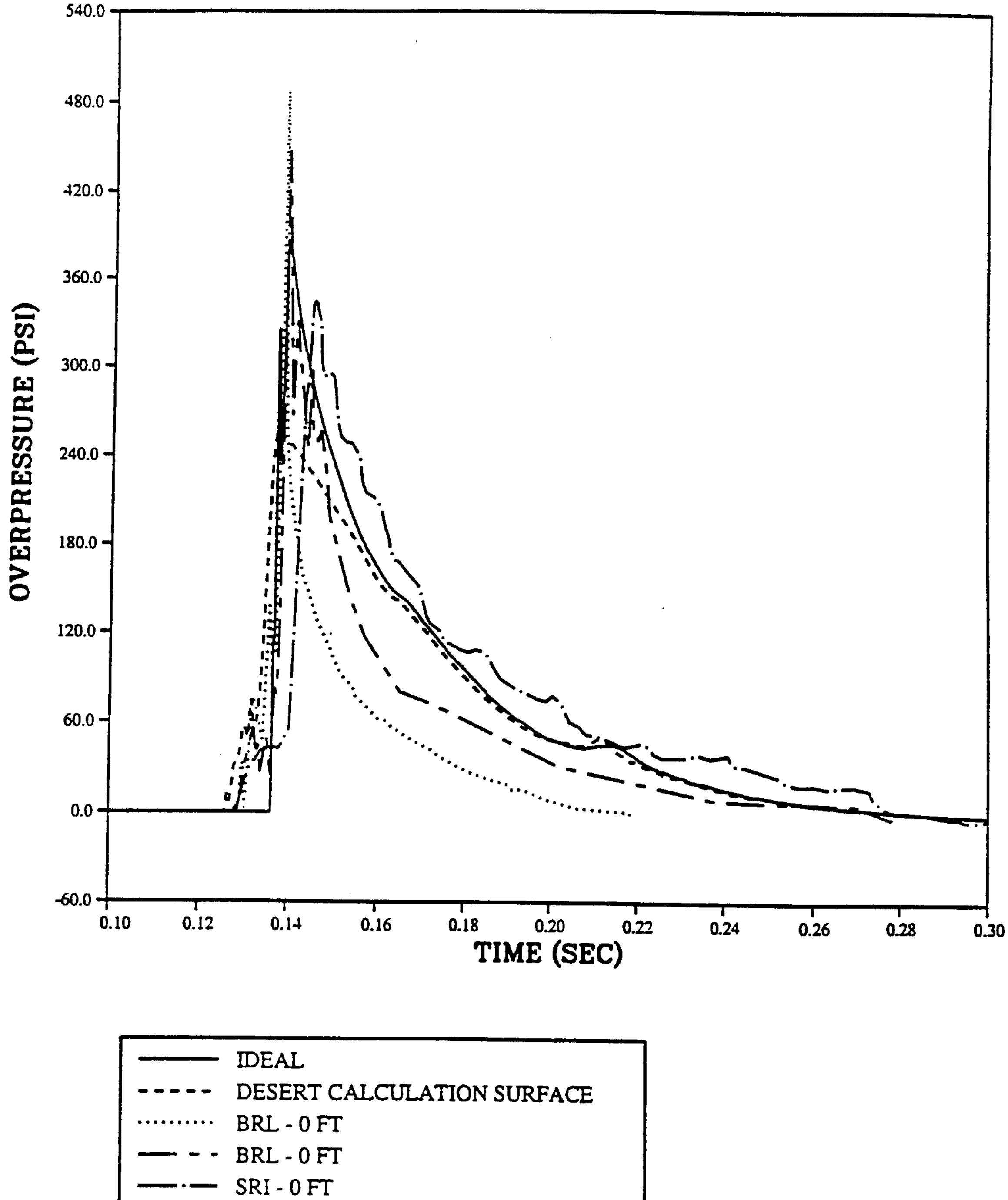
PRISCILLA
CALCULATION - DATA COMPARISONS
OVERPRESSURE AT 450 FEET (137 M)



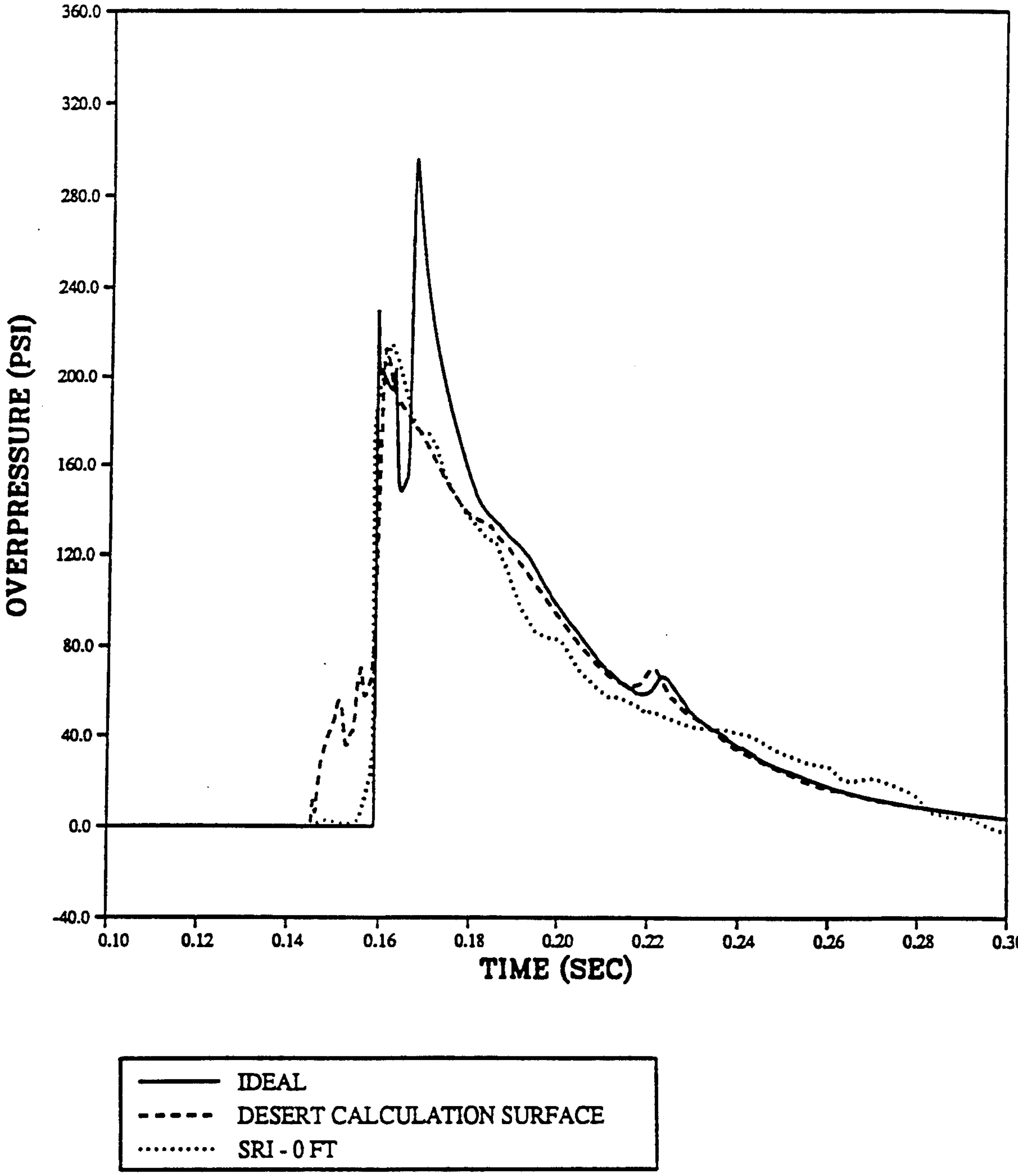
PRISCILLA
CALCULATION - DATA COMPARISONS
OVERPRESSURE AT 550 FEET (168 M)



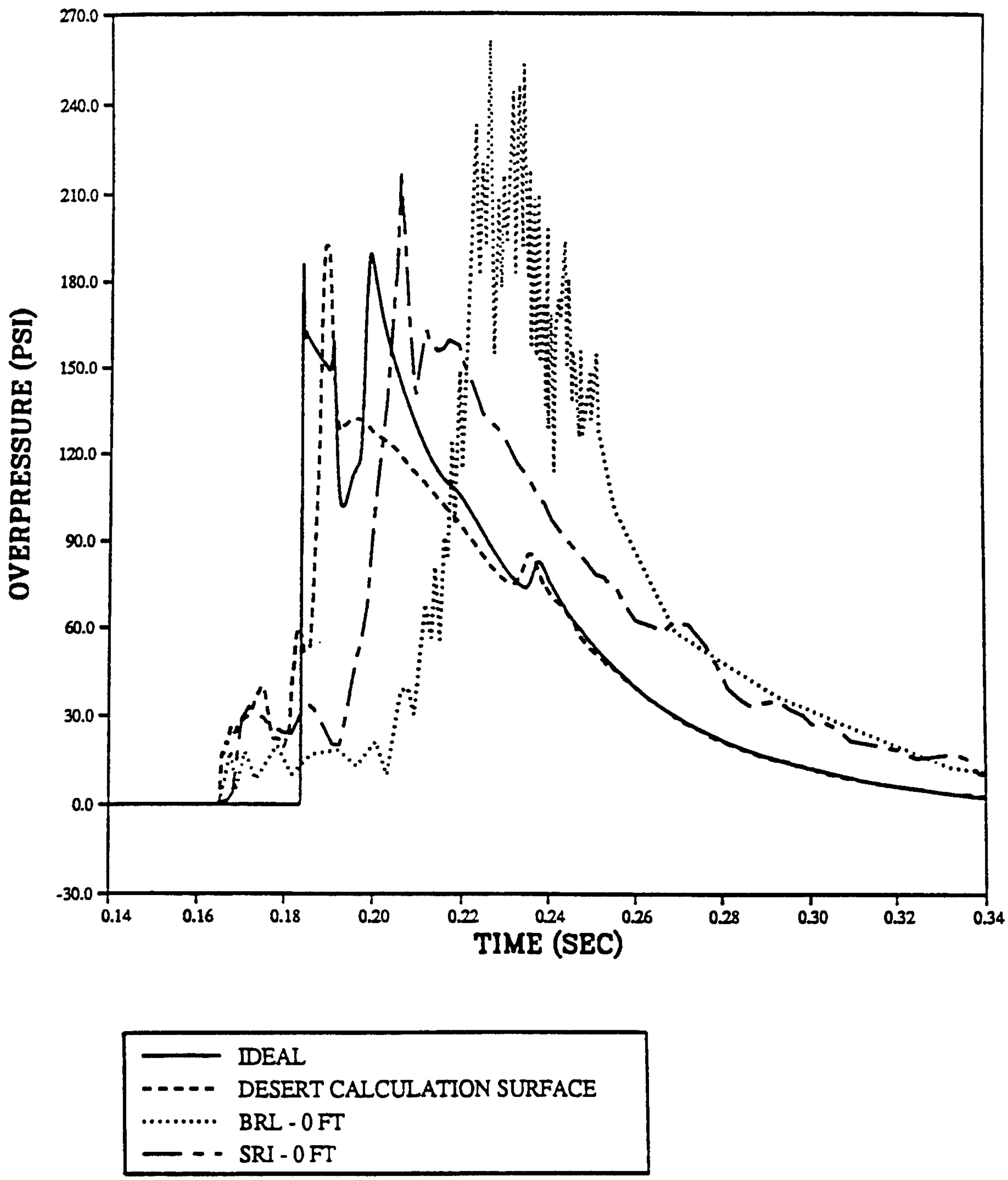
PRISCILLA
CALCULATION - DATA COMPARISONS
OVERPRESSURE AT 650 FEET (198 M)



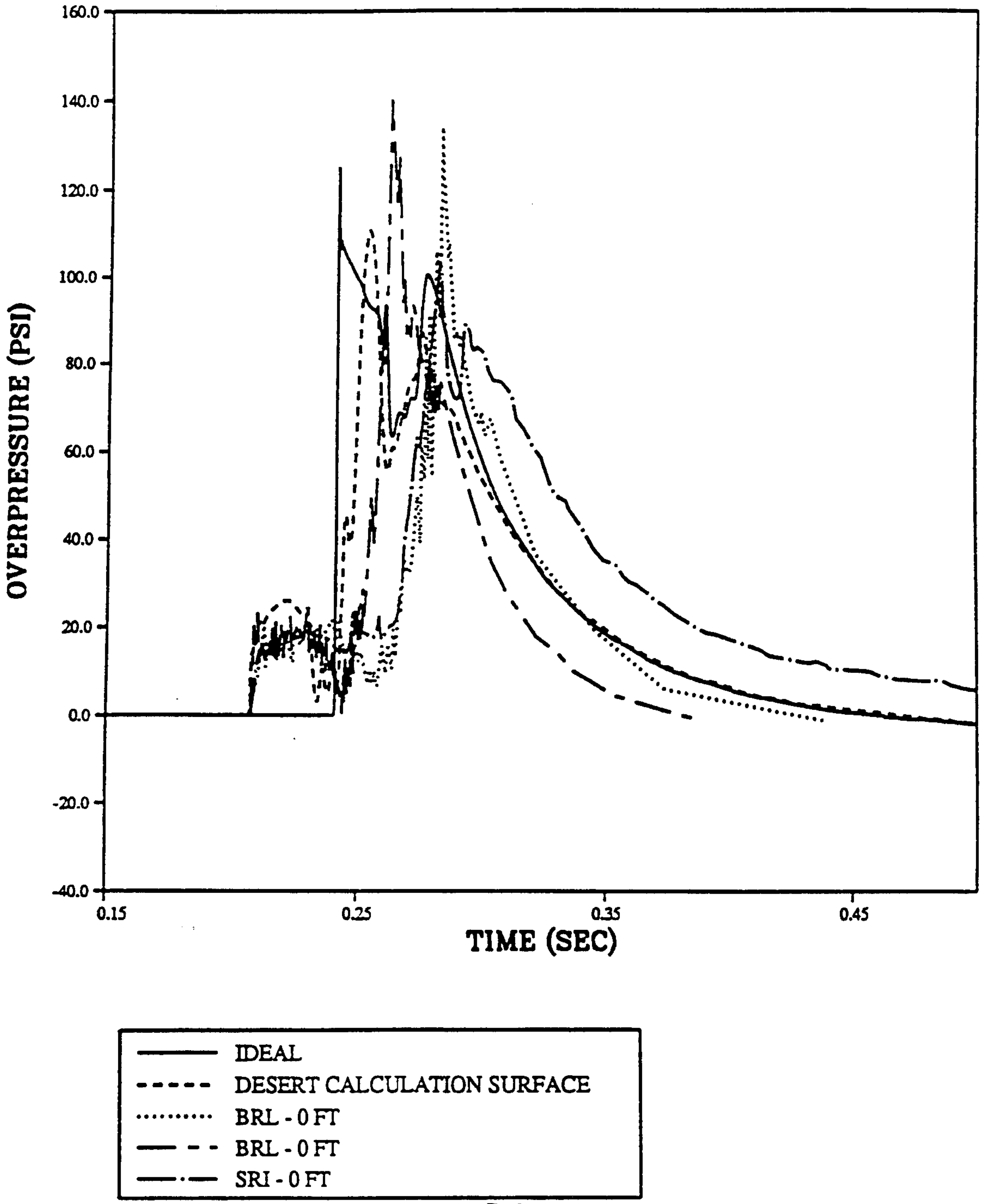
PRISCILLA
CALCULATION - DATA COMPARISONS
OVERPRESSURE AT 750 FEET (229 M)



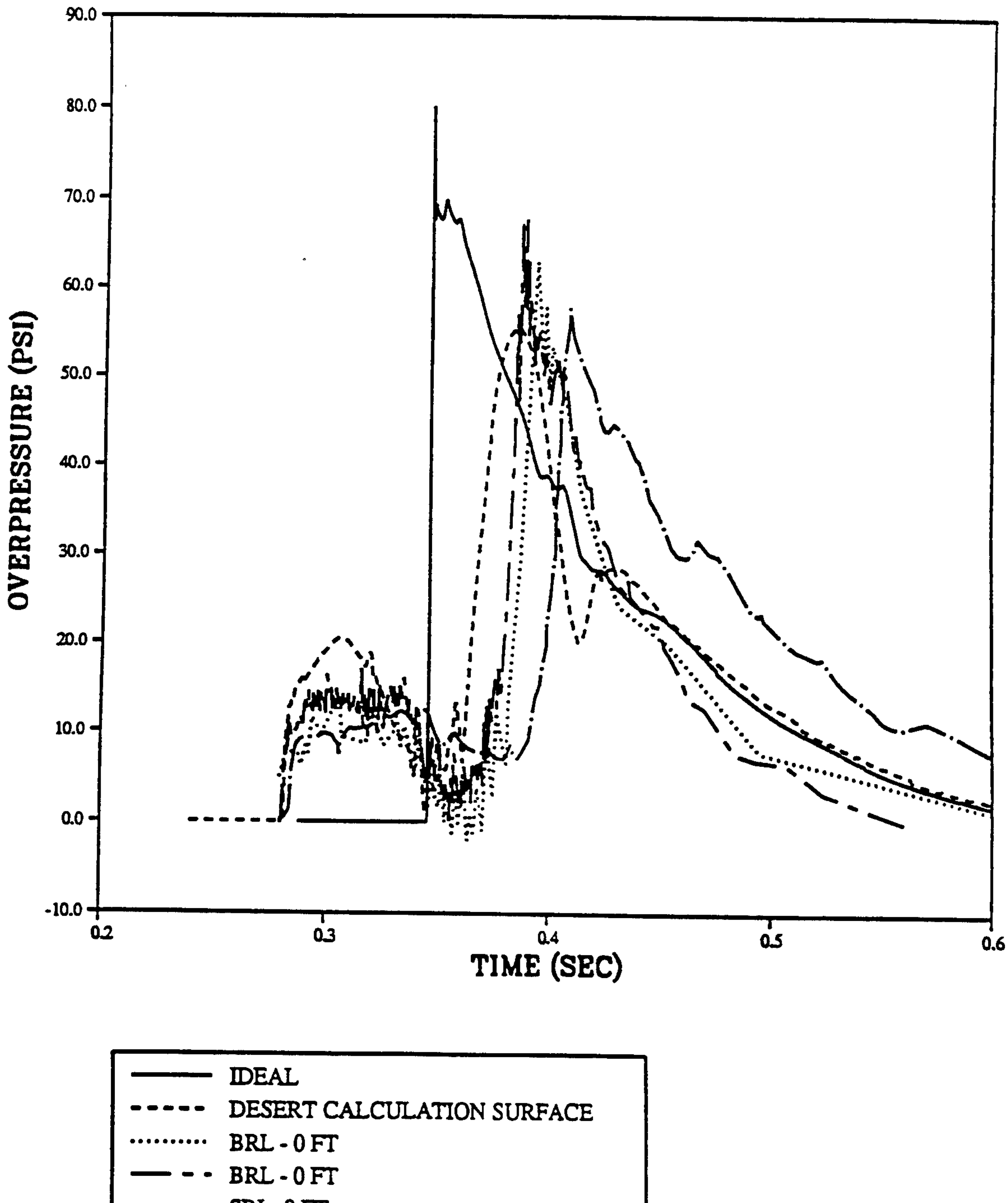
PRISCILLA
CALCULATION - DATA COMPARISONS
OVERPRESSURE AT 850 FEET (260 M)



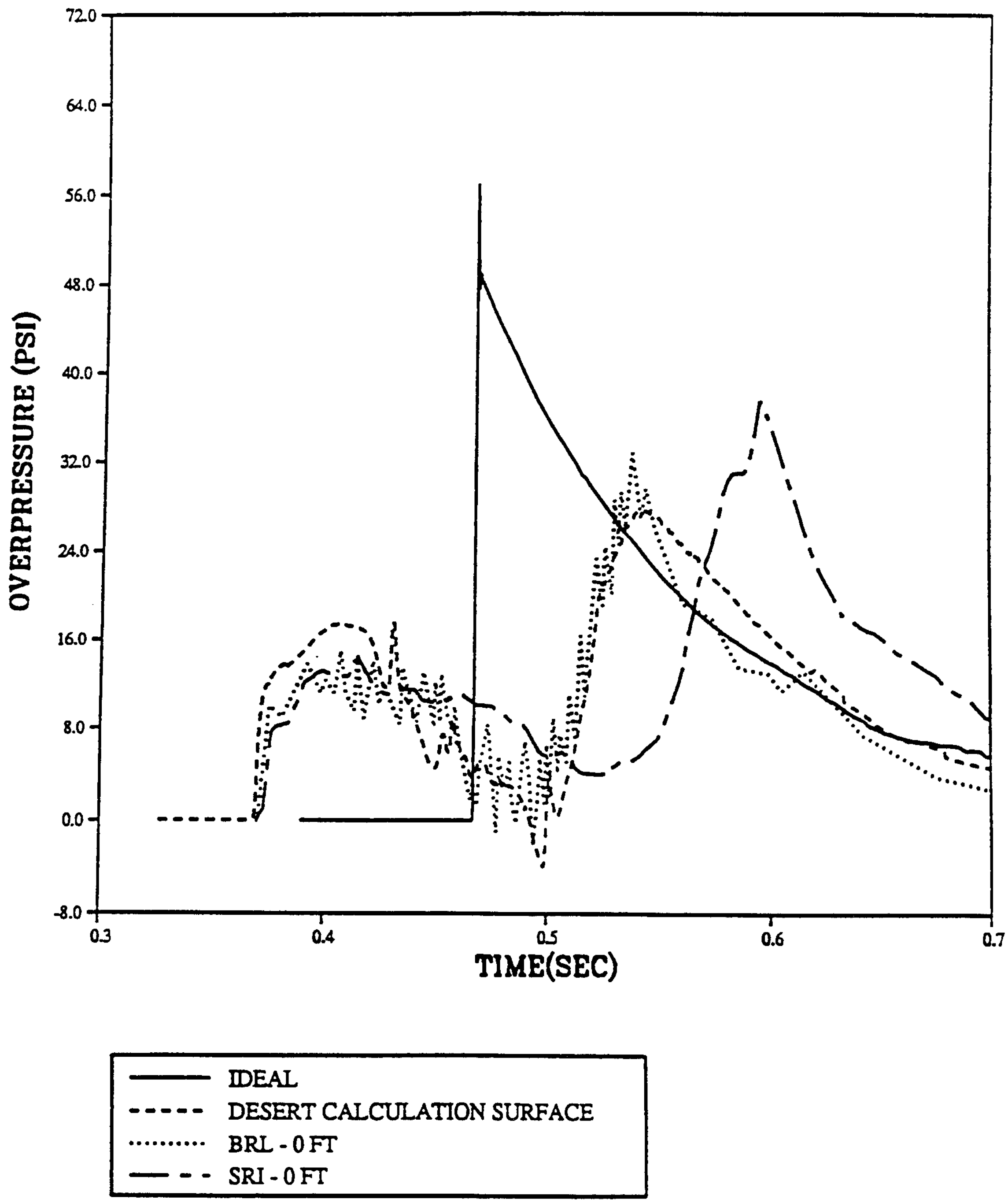
PRISCILLA
CALCULATION - DATA COMPARISONS
OVERPRESSURE AT 1050 FEET (320 M)



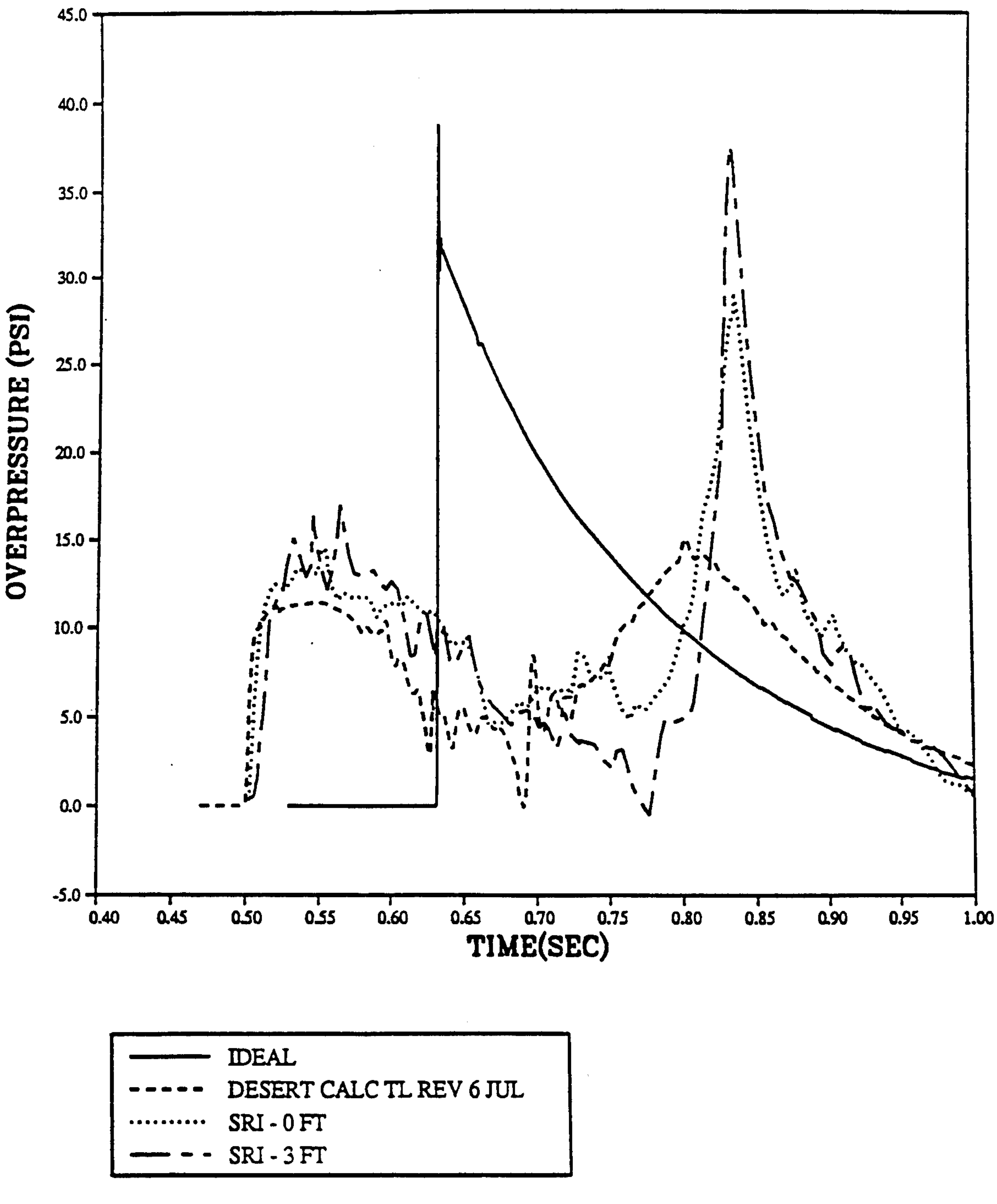
PRISCILLA
CALCULATION - DATA COMPARISONS
OVERPRESSURE AT 1350 FEET (410 M)



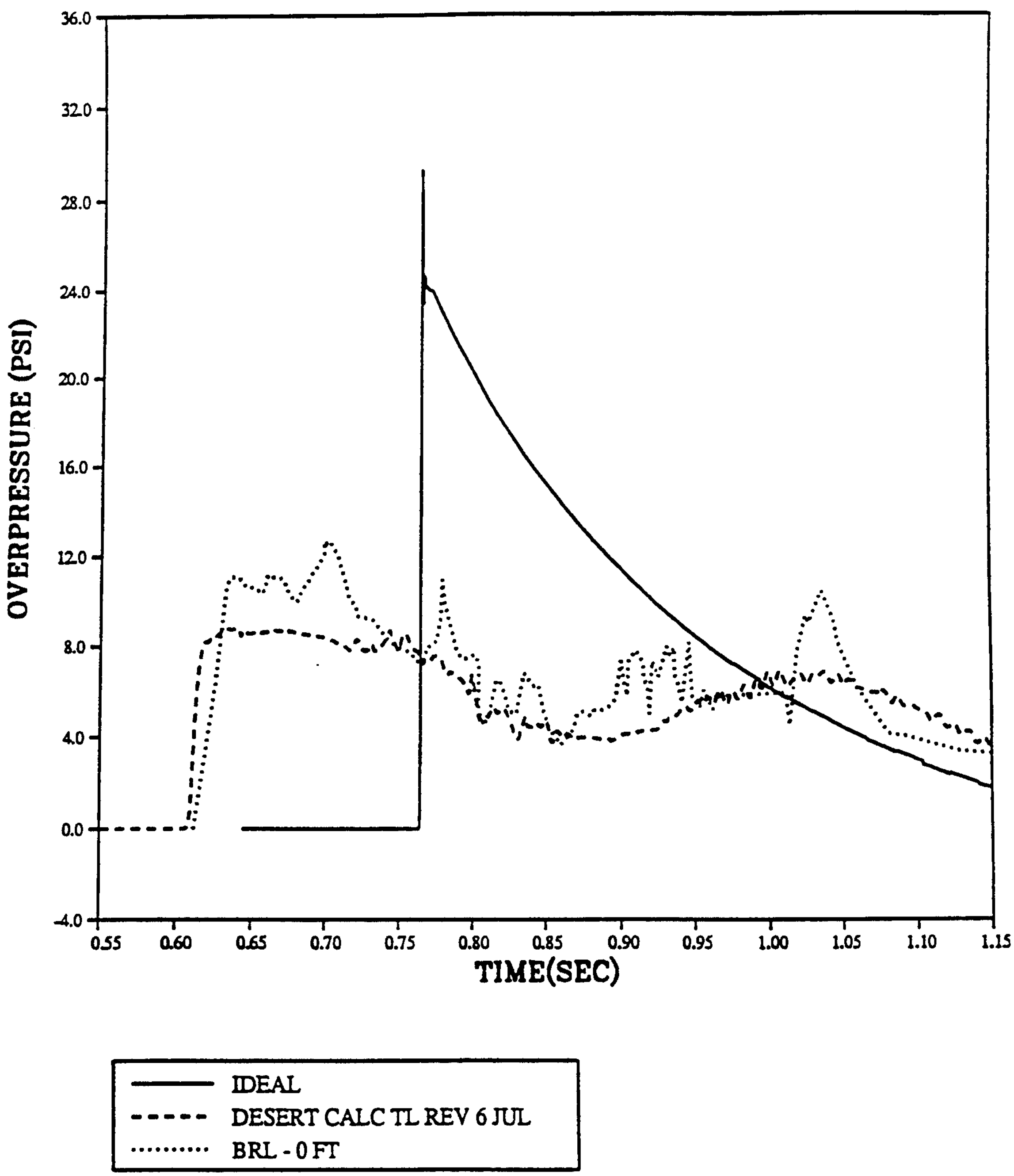
PRISCILLA
CALCULATION - DATA COMPARISONS
OVERPRESSURE AT 1650 FEET (503 M)



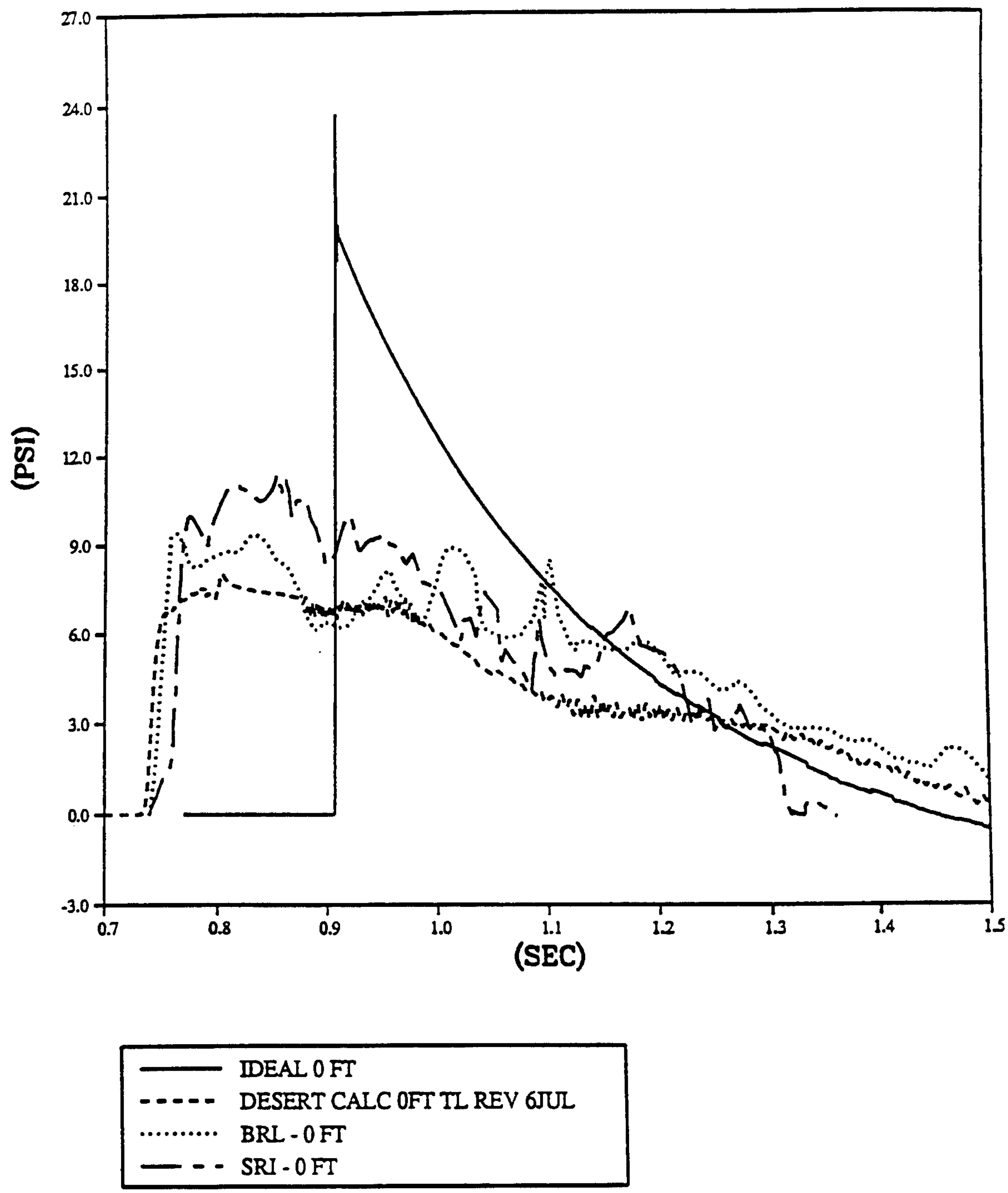
PRISCILLA
CALCULATION - DATA COMPARISONS
OVERPRESSURE AT 2000 FEET (610 M)



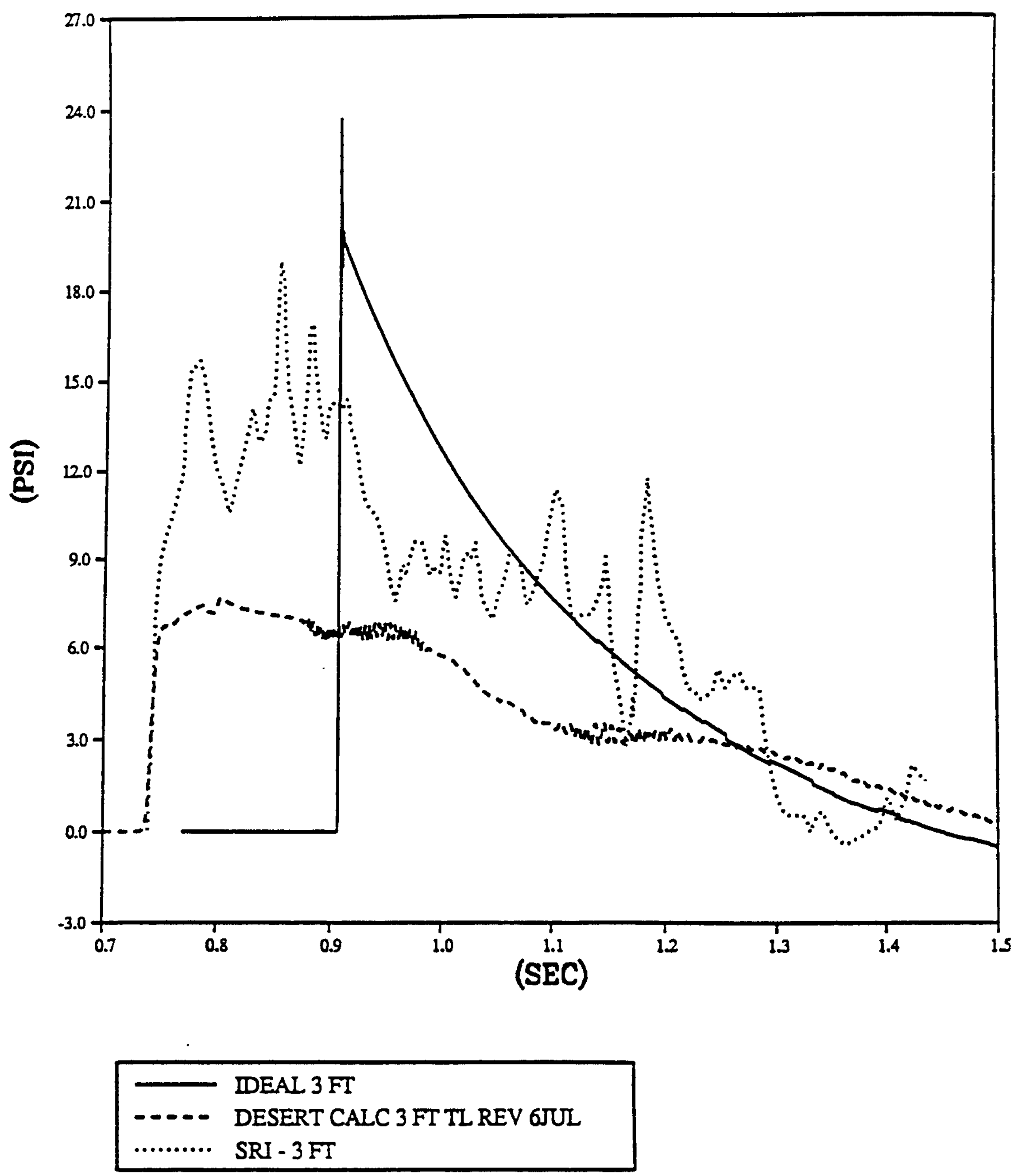
PRISCILLA
CALCULATION - DATA COMPARISONS
OVERPRESSURE AT 2250 FEET (686 M)



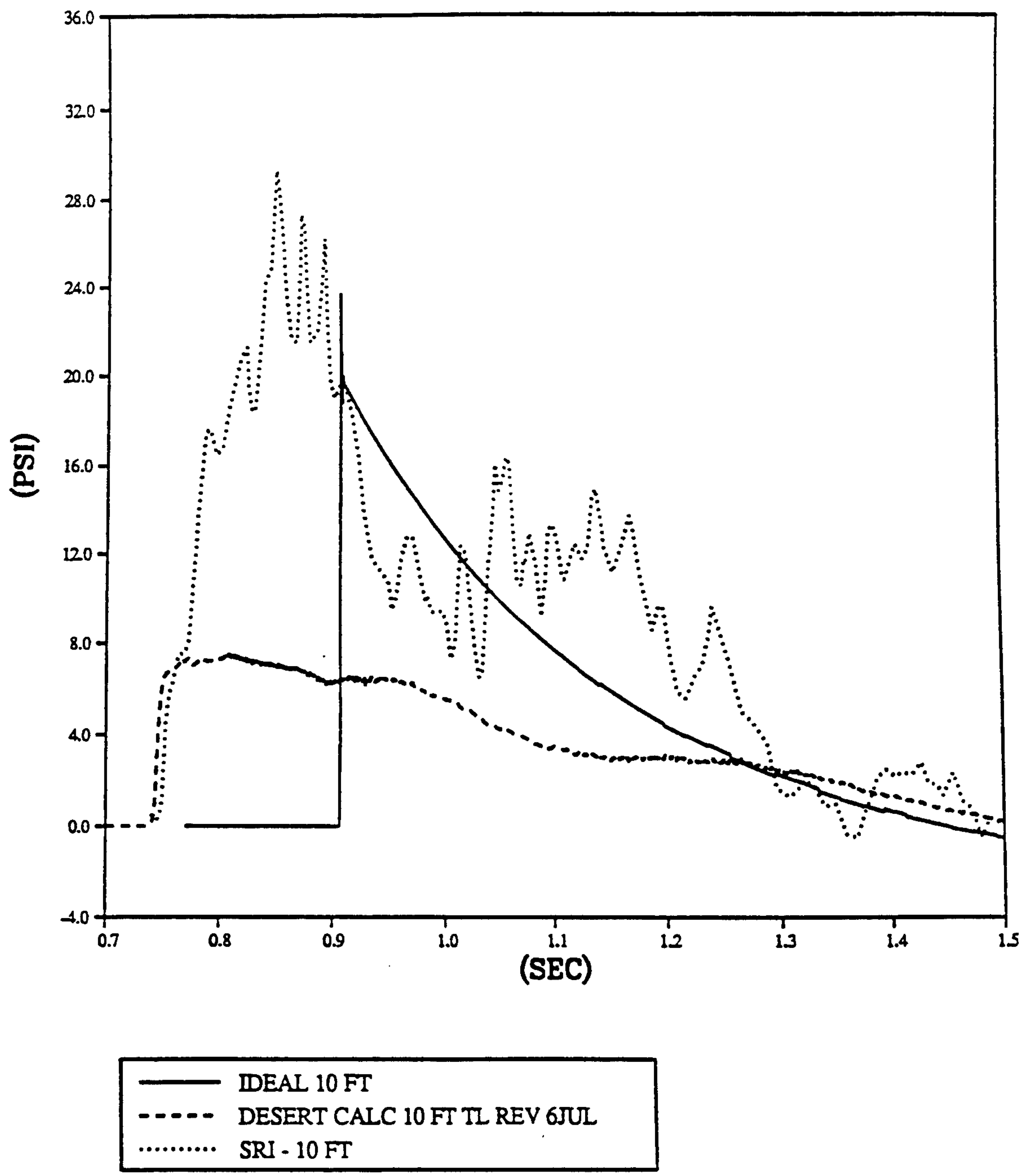
PRISCILLA
CALCULATION - DATA COMPARISONS
OVERPRESSURE AT 2500 FEET (762 M)



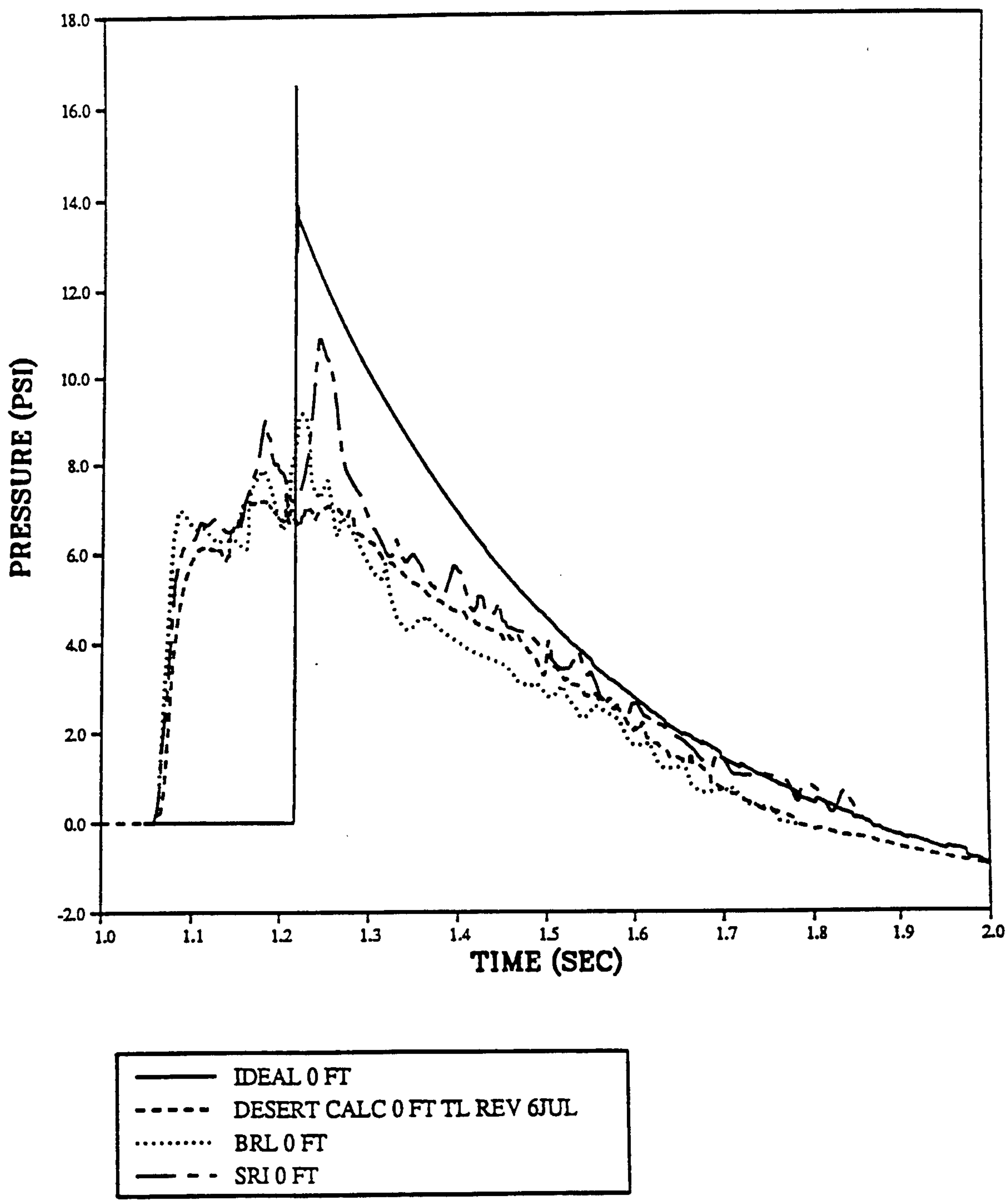
PRISCILLA
CALCULATION - DATA COMPARISONS
OVERPRESSURE AT 2500 FEET (762 M)



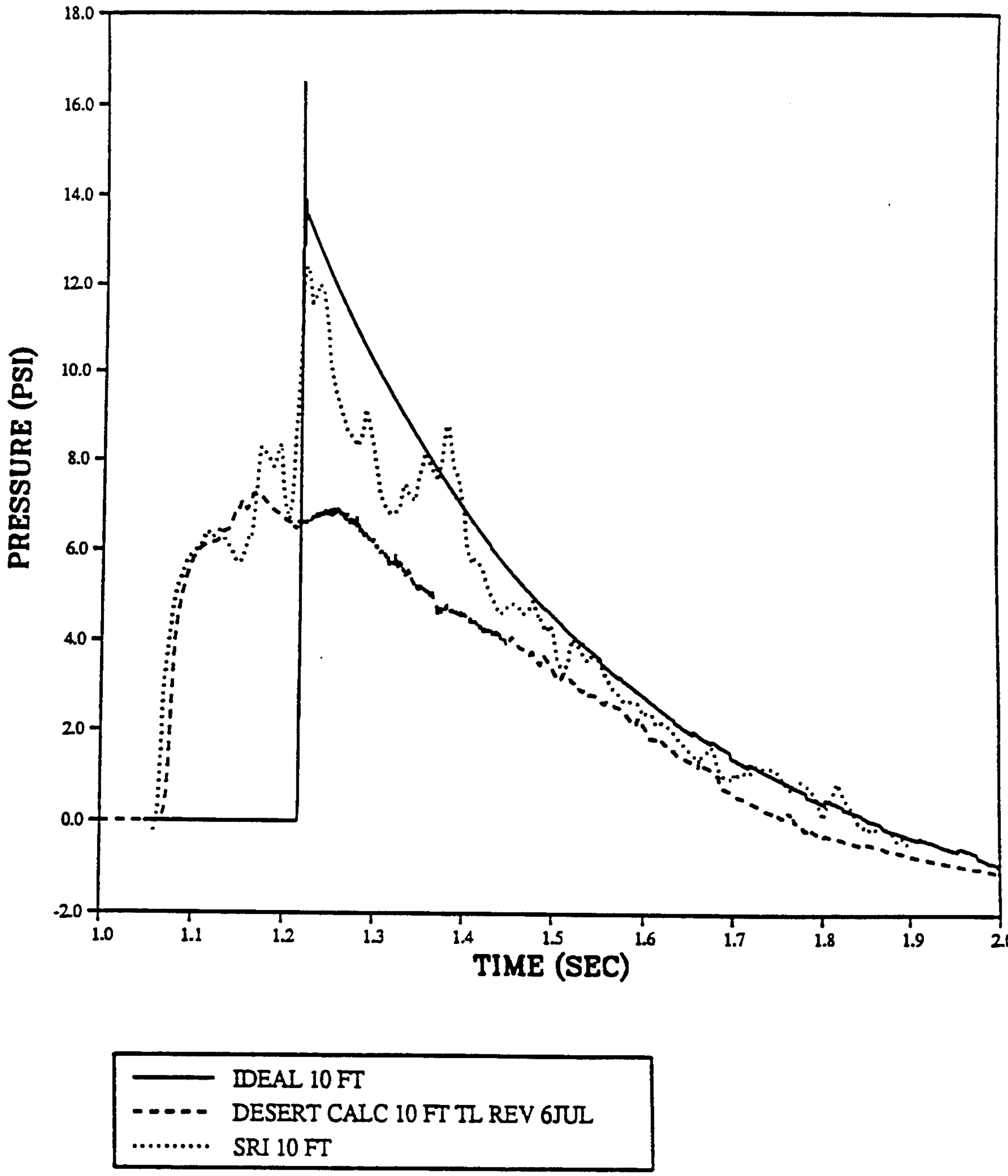
PRISCILLA
CALCULATION - DATA COMPARISONS
OVERPRESSURE AT 2500 FEET (762 M)



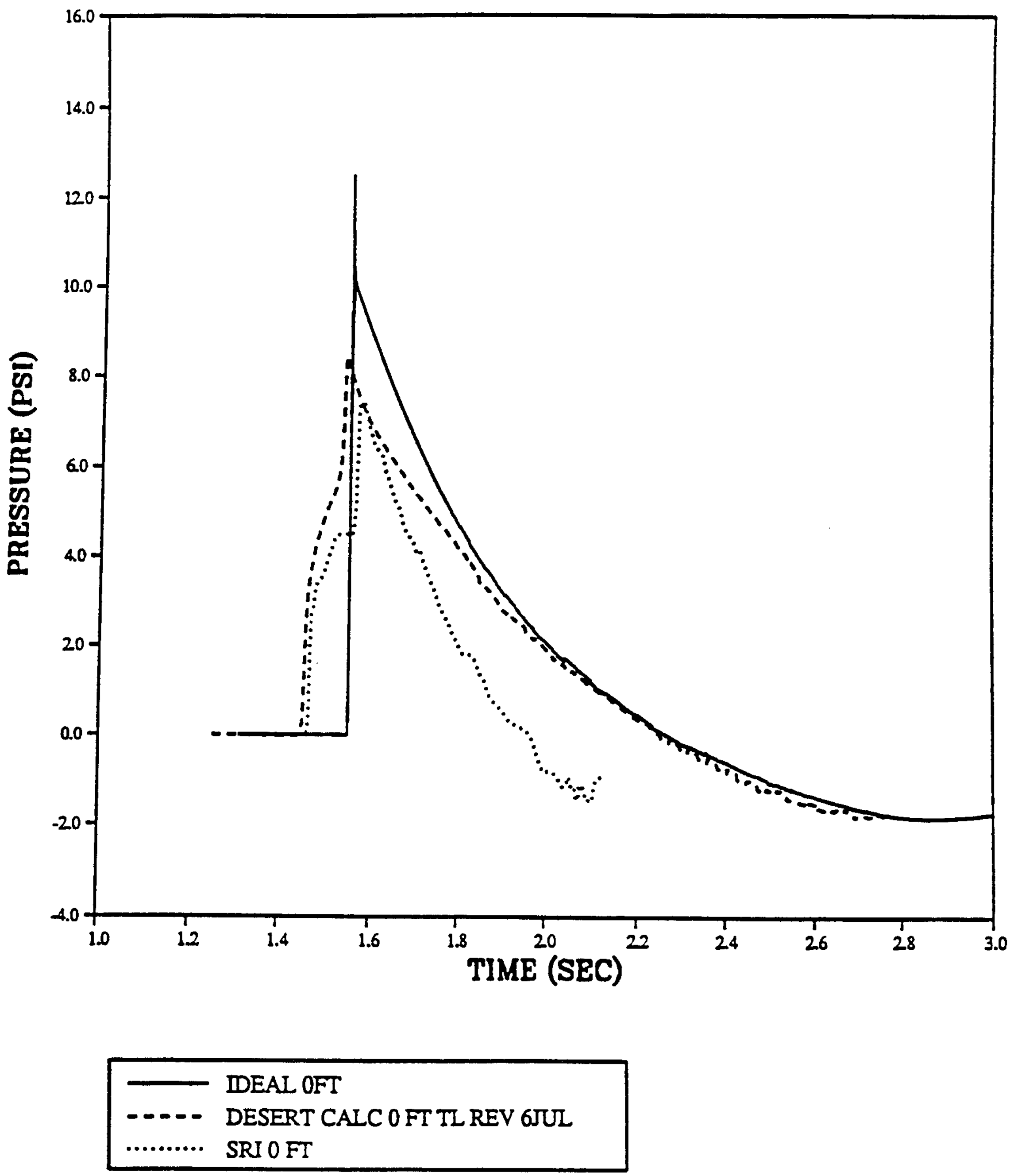
PRISCILLA
CALCULATION - DATA COMPARISONS
OVERPRESSURE AT 3000 FEET (914 M)



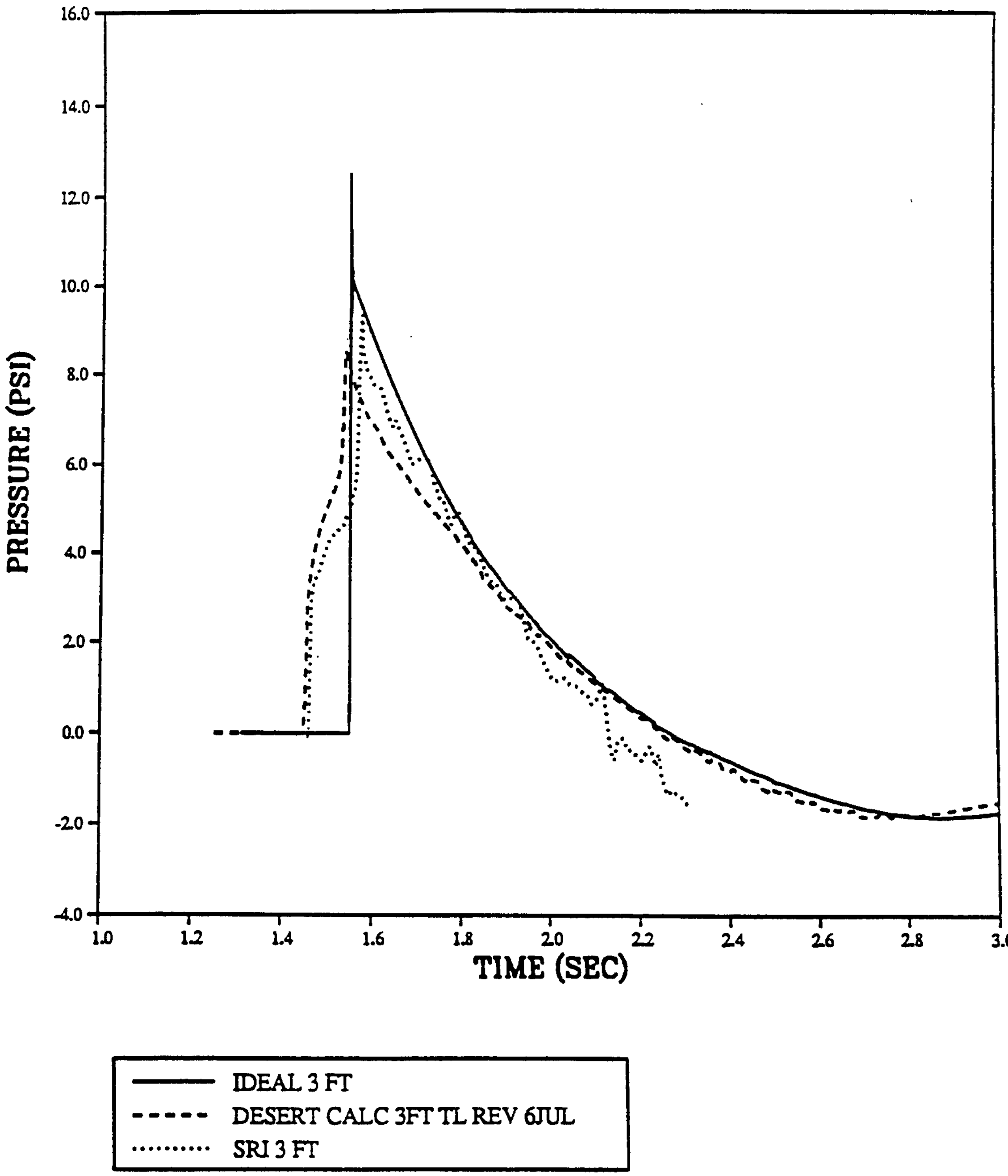
PRISCILLA
CALCULATION - DATA COMPARISONS
OVERPRESSURE AT 3000 FEET (914 M)



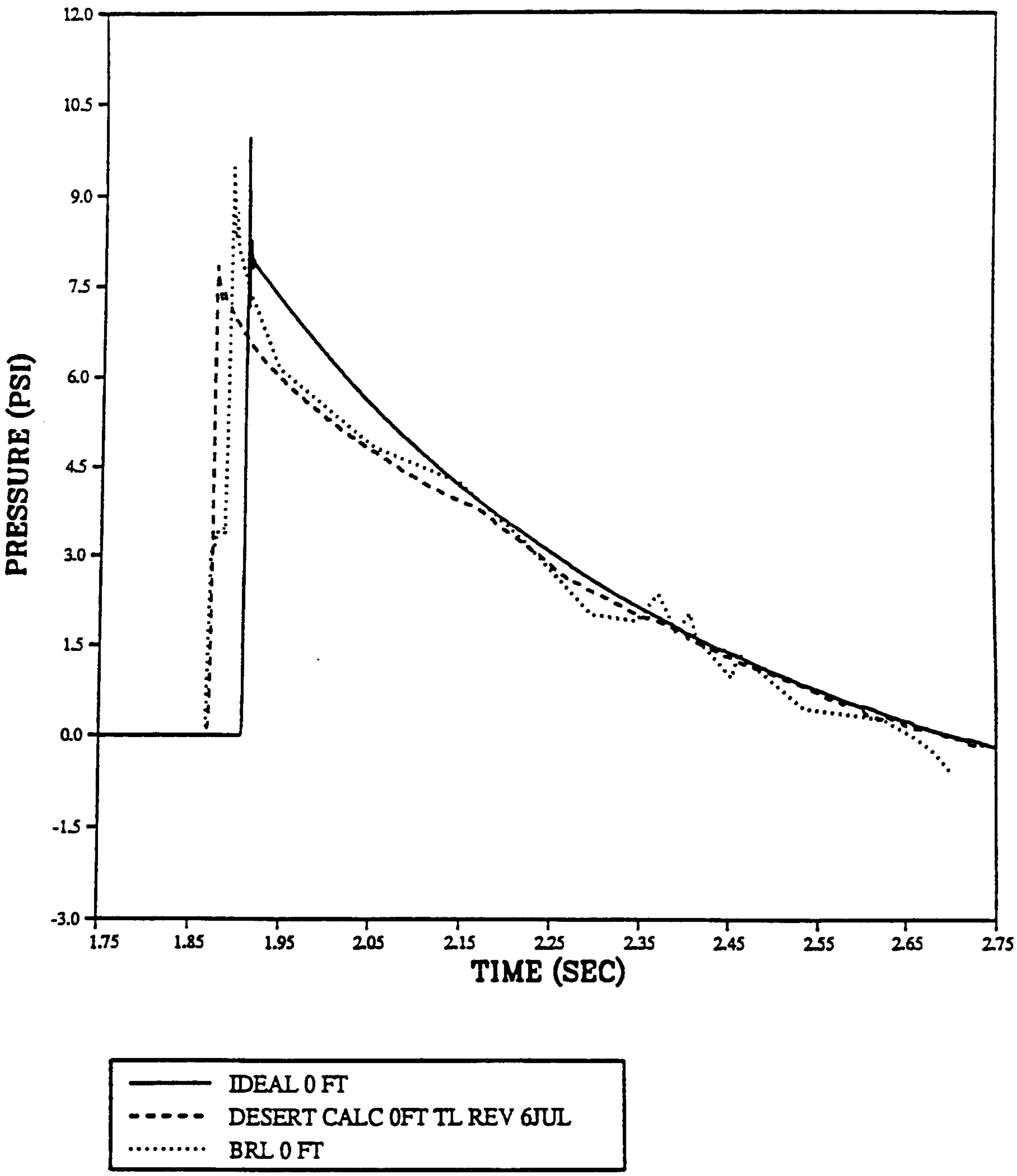
PRISCILLA
CALCULATION - DATA COMPARISONS
OVERPRESSURE AT 3500 FEET (1067 M)



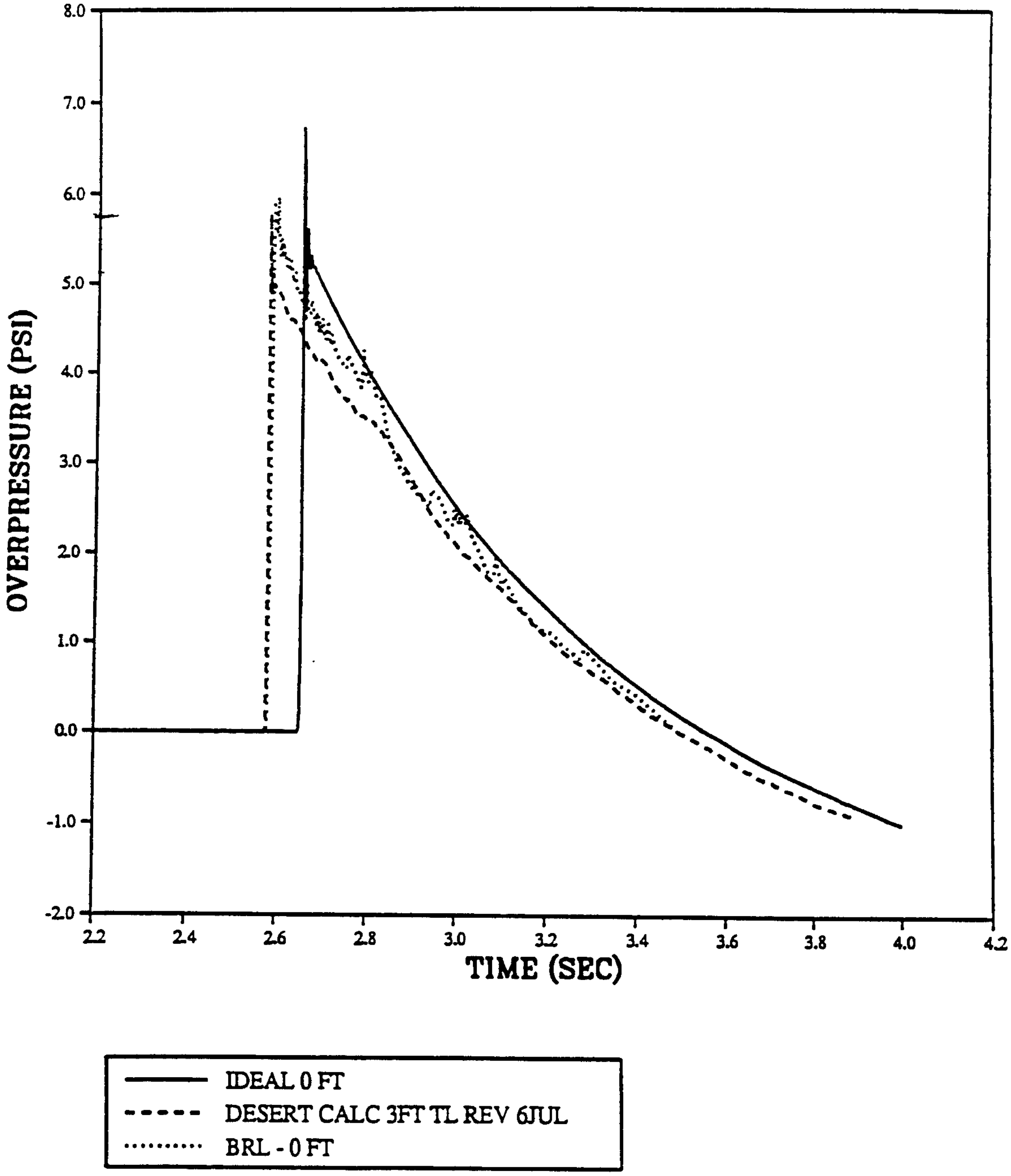
PRISCILLA
CALCULATION - DATA COMPARISONS
OVERPRESSURE AT 3500 FEET (1067 M)



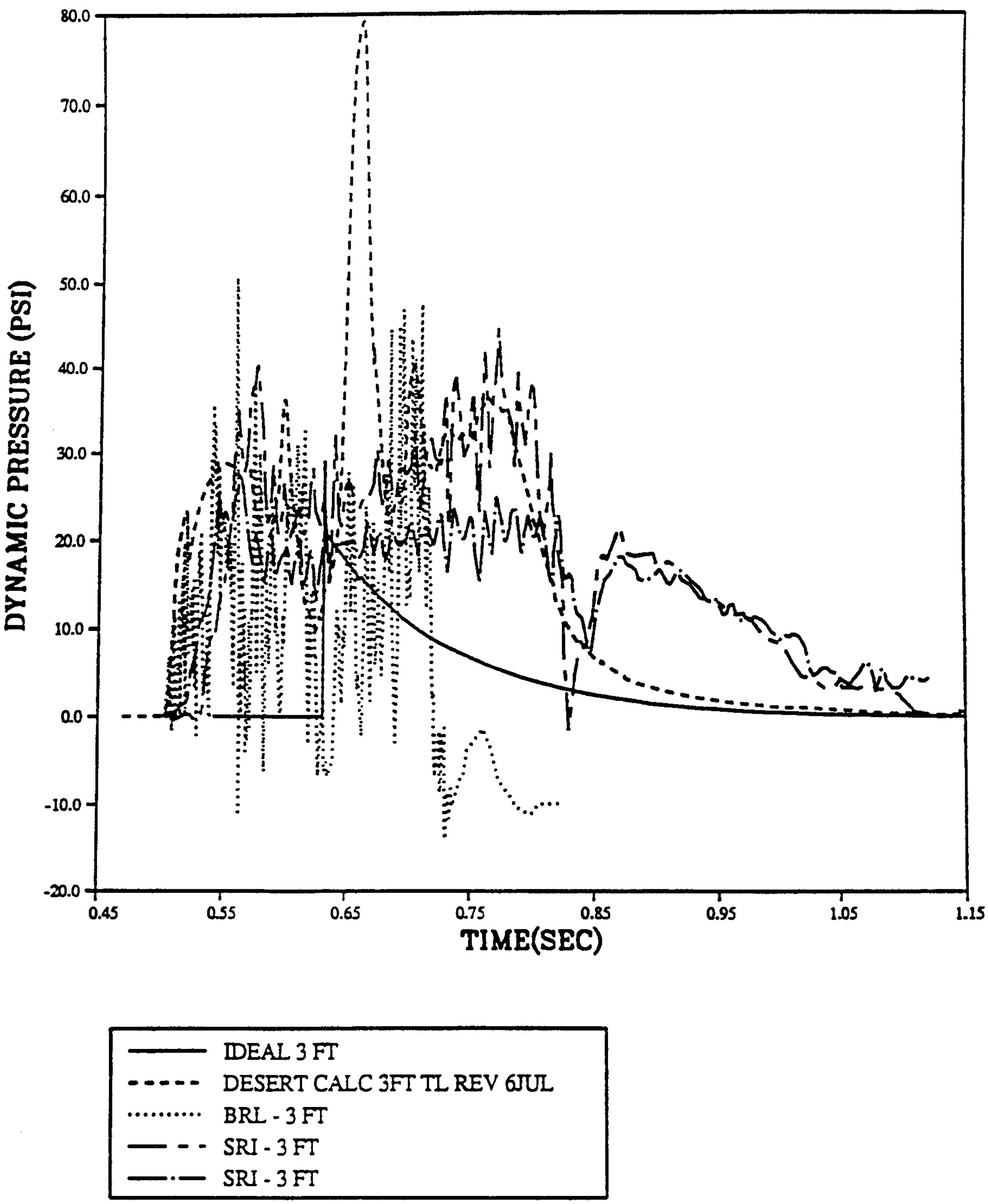
PRISCILLA
CALCULATION - DATA COMPARISONS
OVERPRESSURE AT 4000 FEET (1219 M)



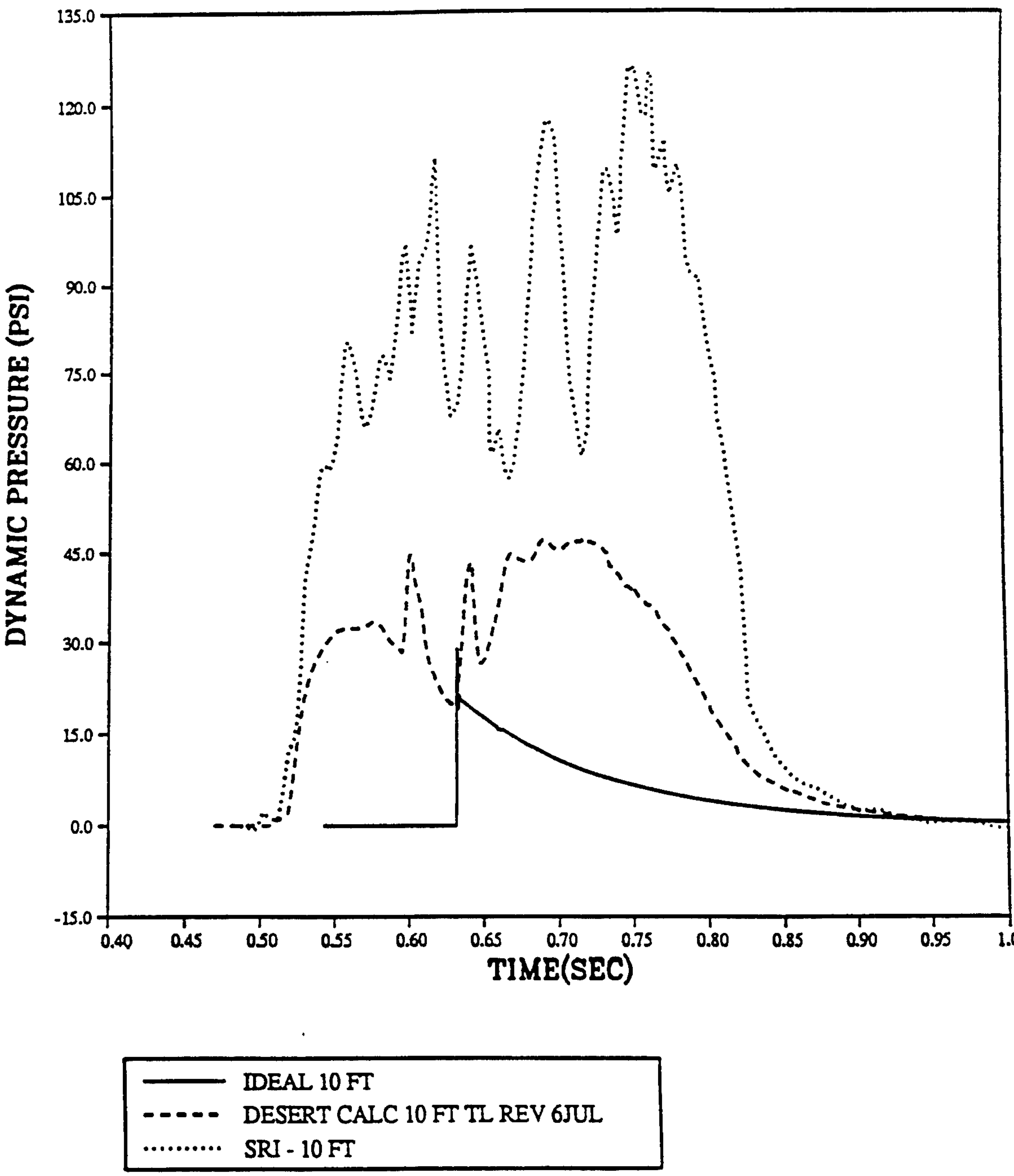
PRISCILLA
CALCULATION - DATA COMPARISONS
OVERPRESSURE AT 5000 FEET (1524 M)



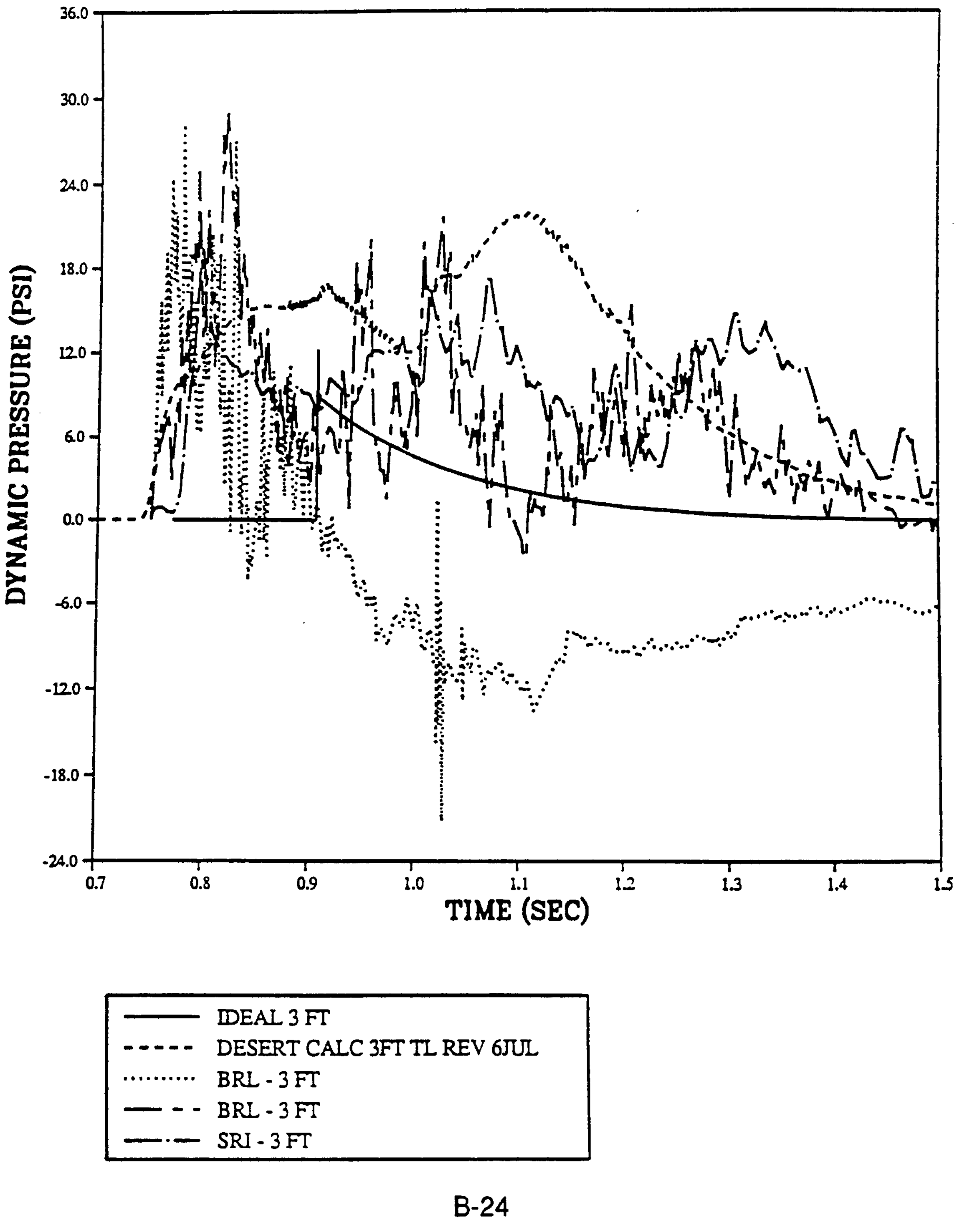
PRISCILLA
CALCULATION - DATA COMPARISONS
DYNAMIC PRESSURE AT 2000 FEET (607 M)



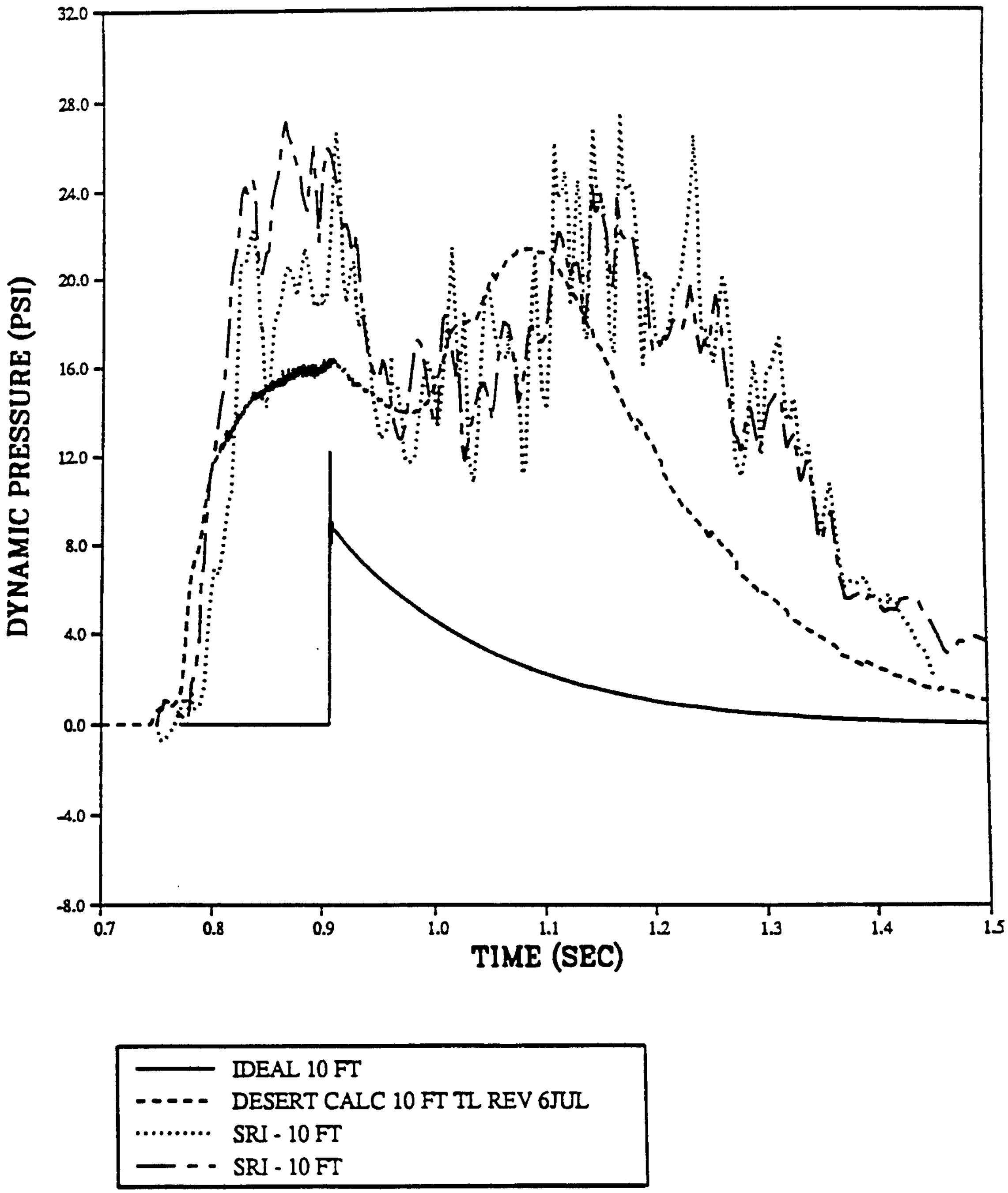
PRISCILLA
CALCULATION - DATA COMPARISONS
DYNAMIC PRESSURE AT 2000 FEET (607 M)



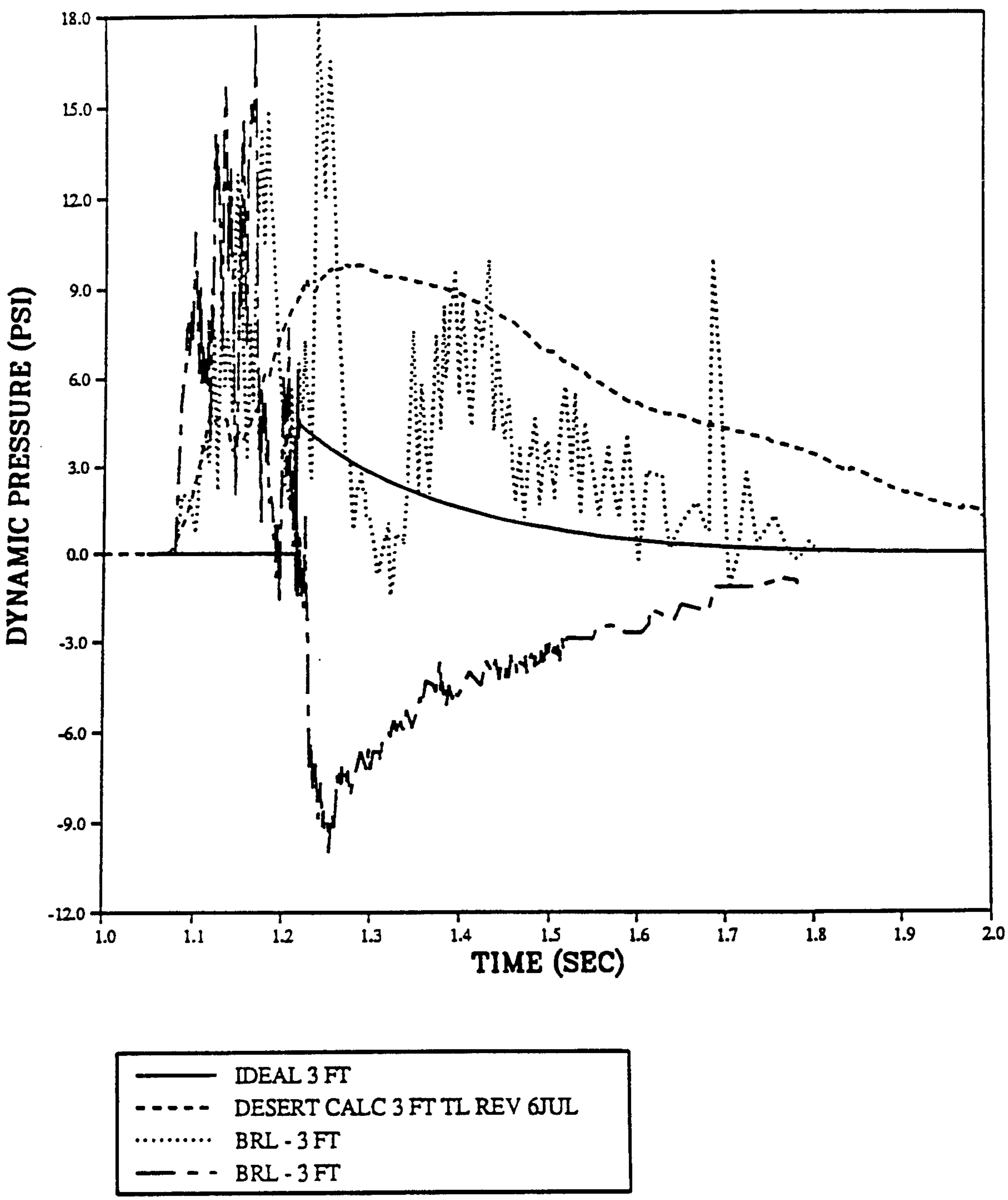
PRISCILLA
CALCULATION - DATA COMPARISONS
DYNAMIC PRESSURE AT 2500 FEET (762 M)



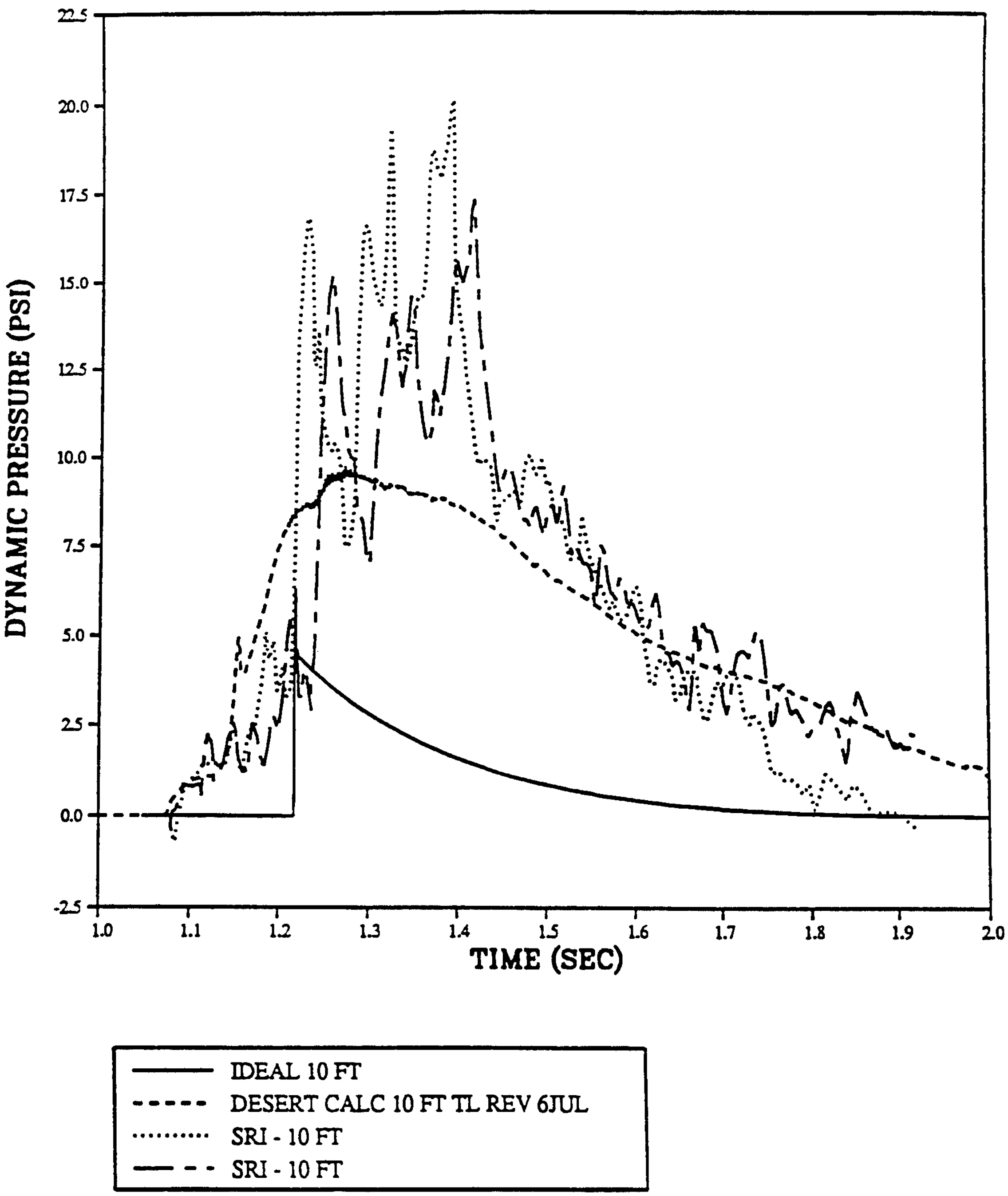
PRISCILLA
CALCULATION - DATA COMPARISONS
DYNAMIC PRESSURE AT 2500 FEET (762 M)



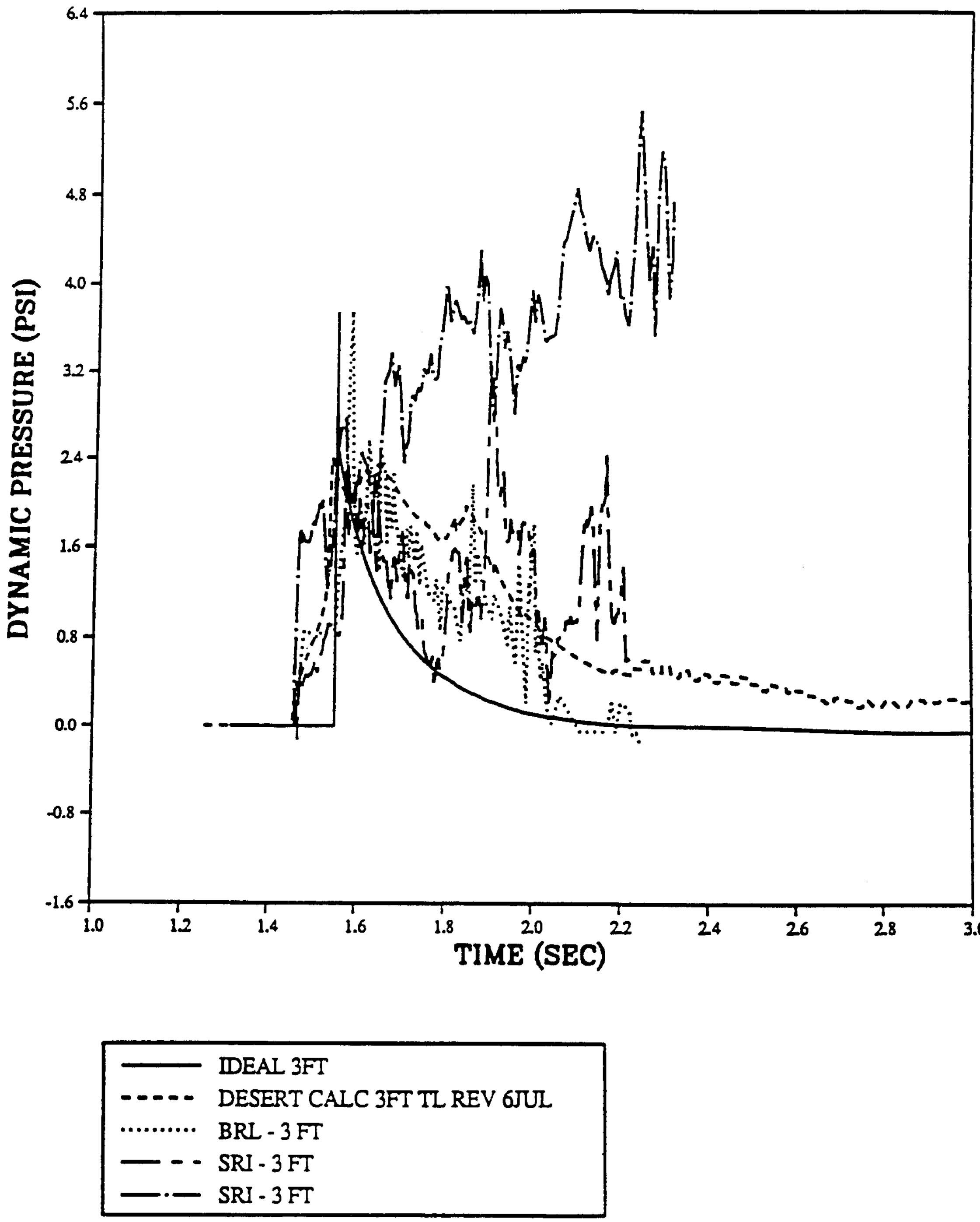
PRISCILLA
CALCULATION - DATA COMPARISONS
DYNAMIC PRESSURE AT 3000 FEET (762 M)



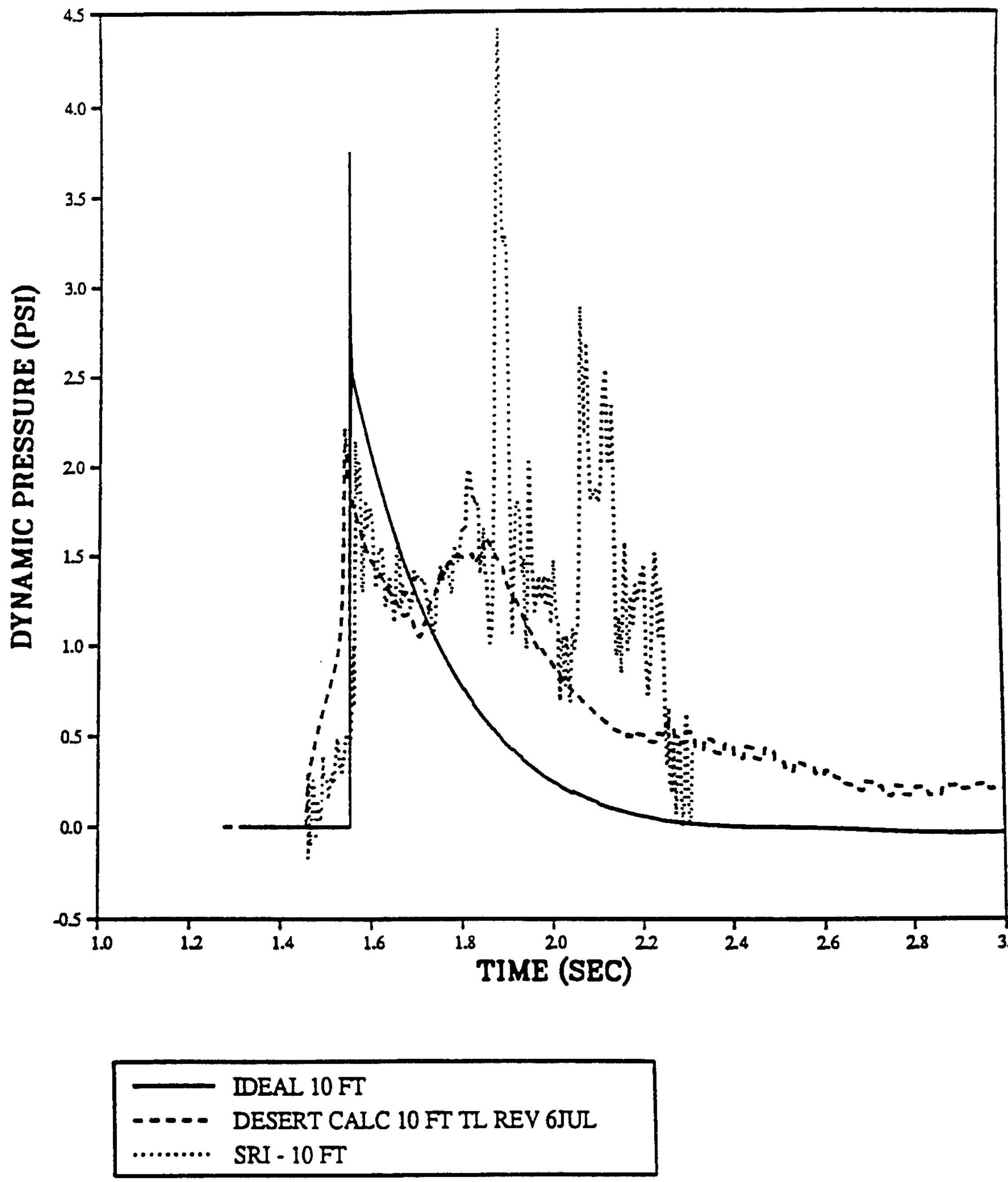
PRISCILLA
CALCULATION - DATA COMPARISONS
DYNAMIC PRESSURE AT 3000 FEET (762 M)



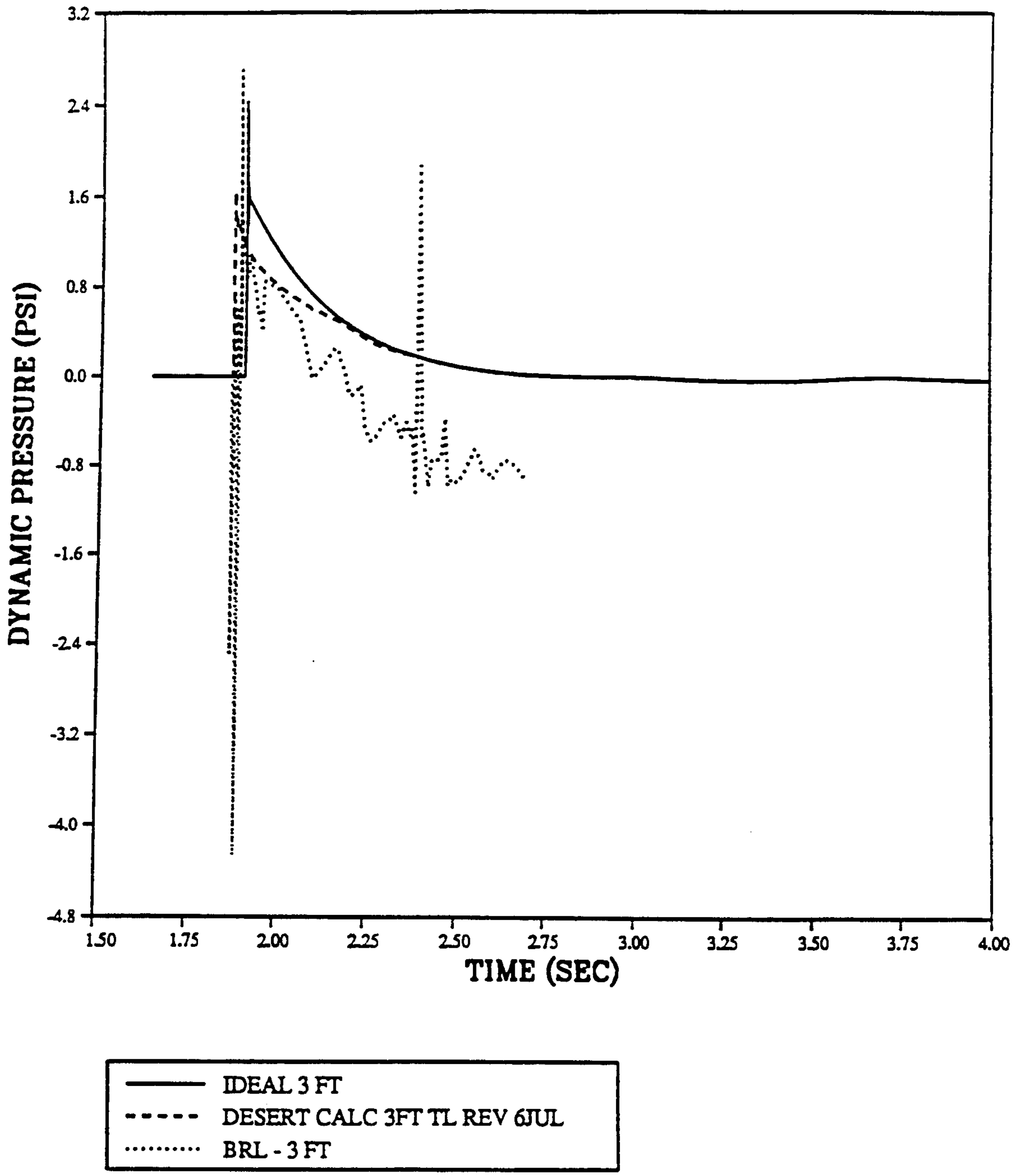
PRISCILLA
CALCULATION - DATA COMPARISONS
DYNAMIC PRESSURE AT 3500 FEET (1067 M)



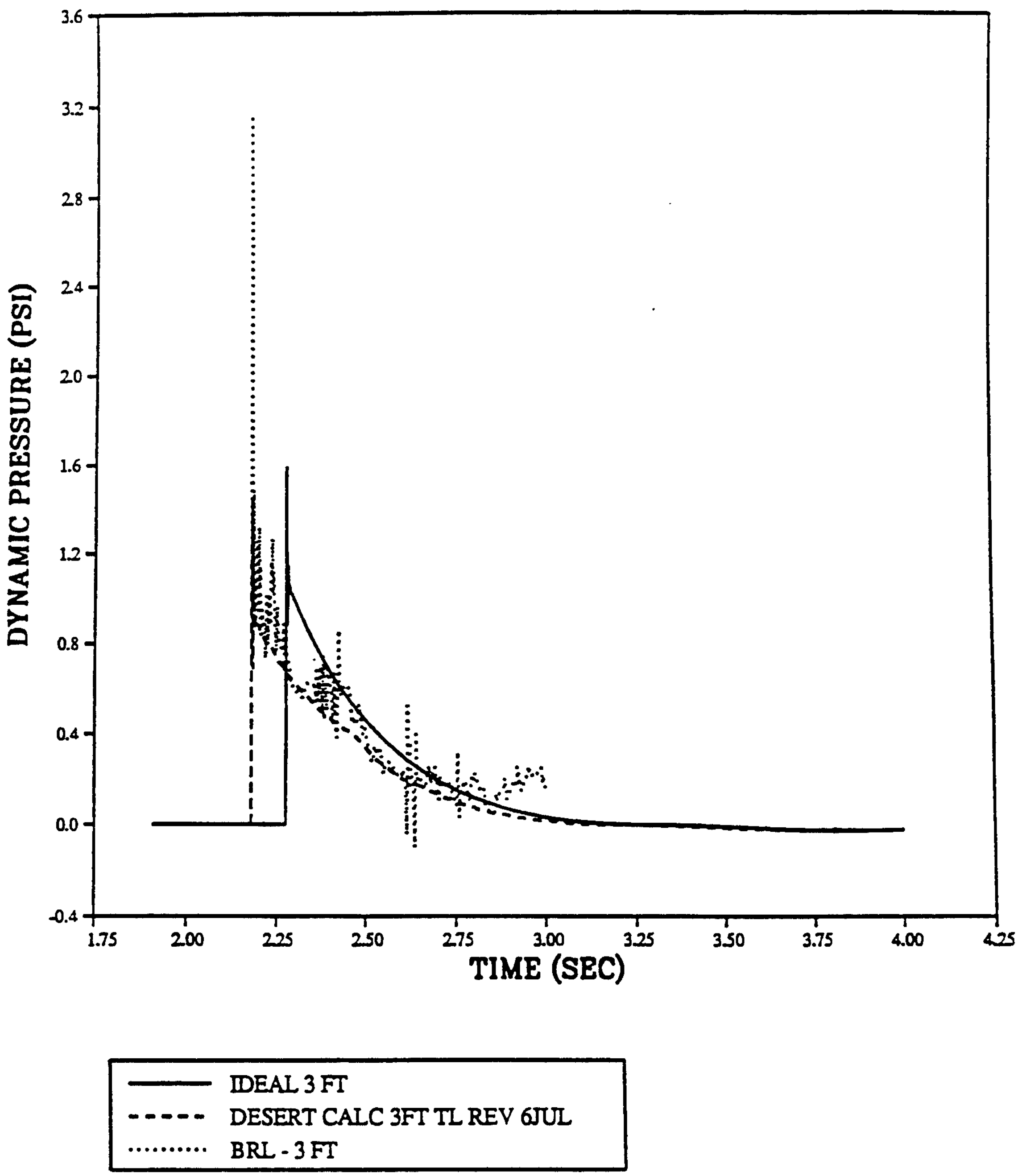
PRISCILLA
CALCULATION - DATA COMPARISONS
DYNAMIC PRESSURE AT 3500 FEET (1067 M)



PRISCILLA
CALCULATION - DATA COMPARISONS
DYNAMIC PRESSURE AT 4000 FEET (1219 M)



PRISCILLA
CALCULATION - DATA COMPARISONS
DYNAMIC PRESSURE AT 4500 FEET (1372 M)



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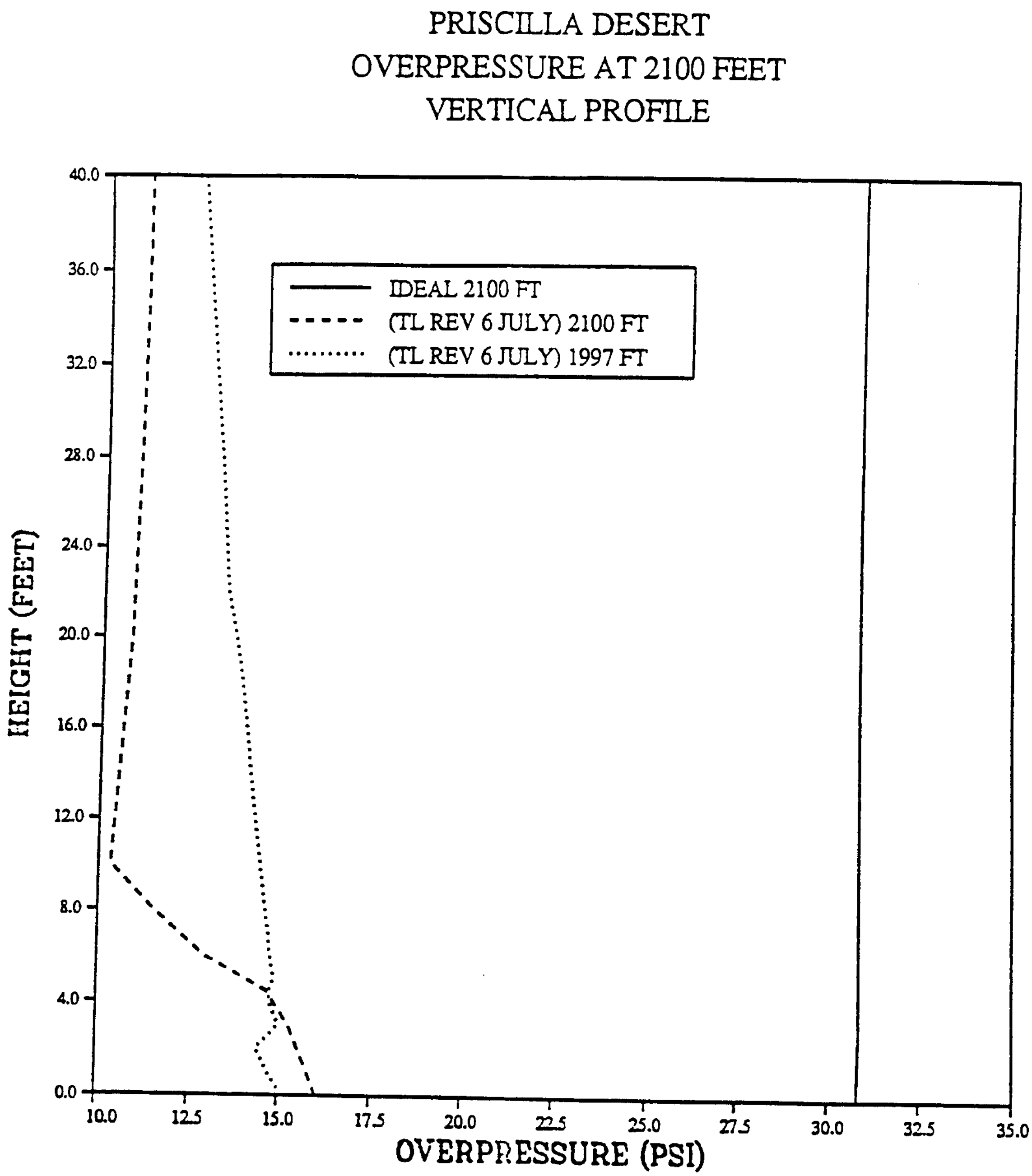
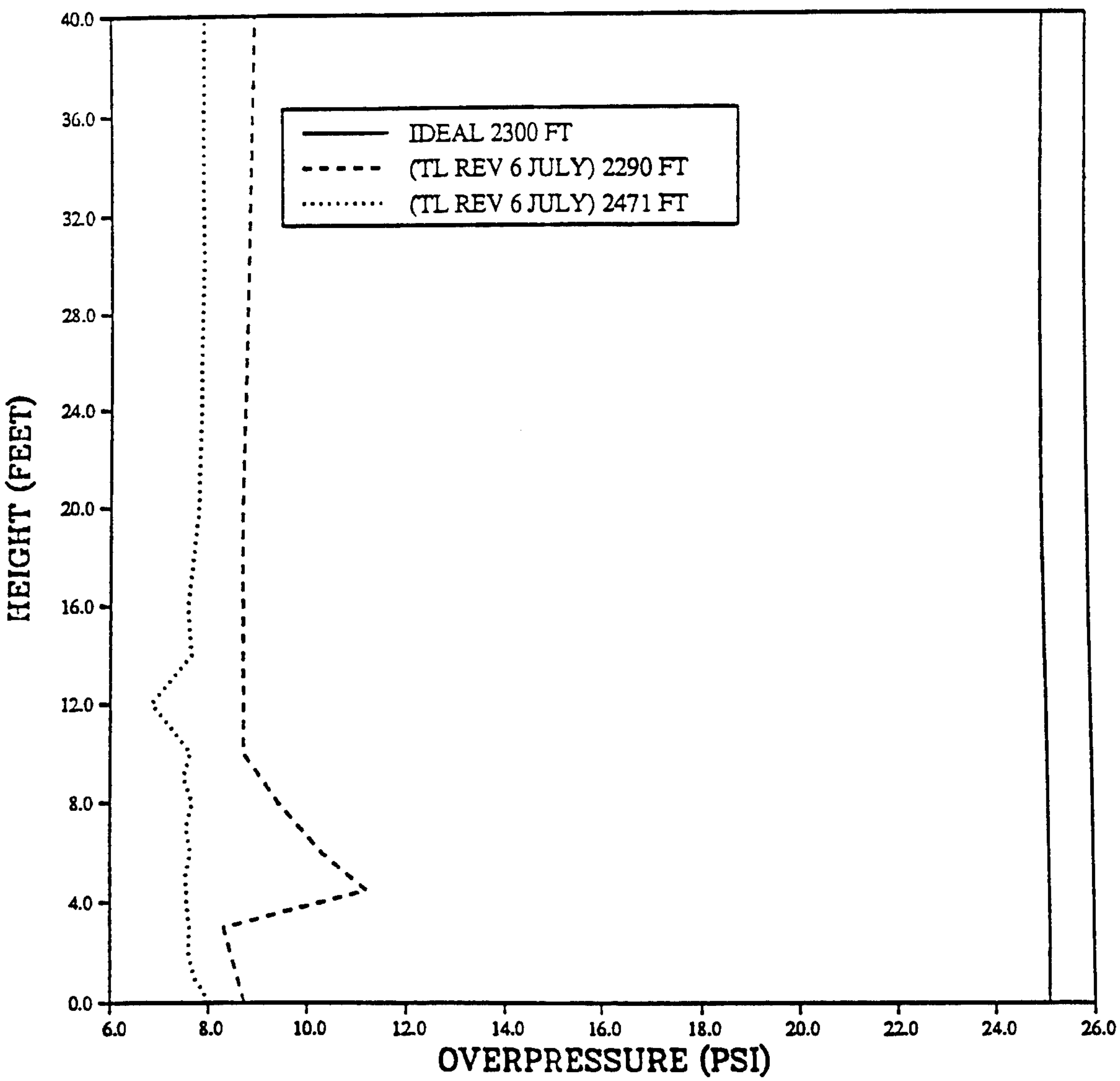
APPENDIX C
HYDRODYNAMIC PARAMETERS AS A FUNCTION OF HEIGHT FOR SELECTED GROUND RANGES

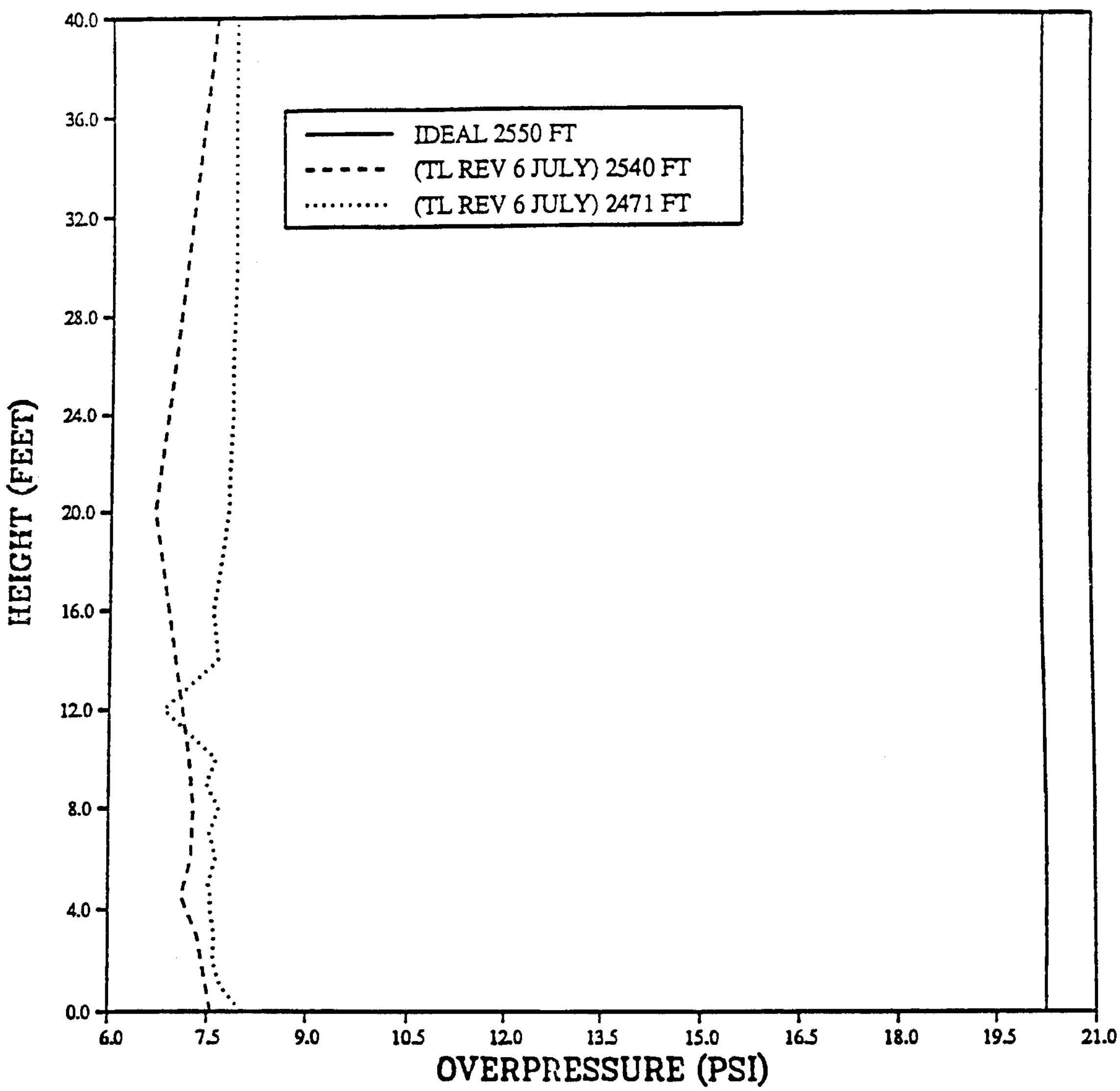
This Appendix contains plots of important hydrodynamic parameters as a function of height above the surface at several ground ranges. The ground ranges were selected on the basis of predicted ideal overpressure levels. Results of calculated ideal and precursor parameters are displayed on each plot. Because of the problem with 32-bit truncation causing the precursor stations to move prior to shock arrival, most of the precursor results include two curves; one on either side of the ideal range.


PRISCILLA DESERT
OVERPRESSURE AT 2100 FEET
VERTICAL PROFILE
IDEAL 2100 FT
(TL REV 6 JULY) 2100 FT
(TL REV 6 JULY) 1997 FT
HEIGHT (FEET)
40.0
36.0
32.0
28.0
24.0
20.0
16.0
12.0
8.0
4.0
0.0
10.0
12.5
15.0
17.5
20.0
22.5
25.0
27.5
30.0
32.5
35.0
OVERPRESSURE (PSI)

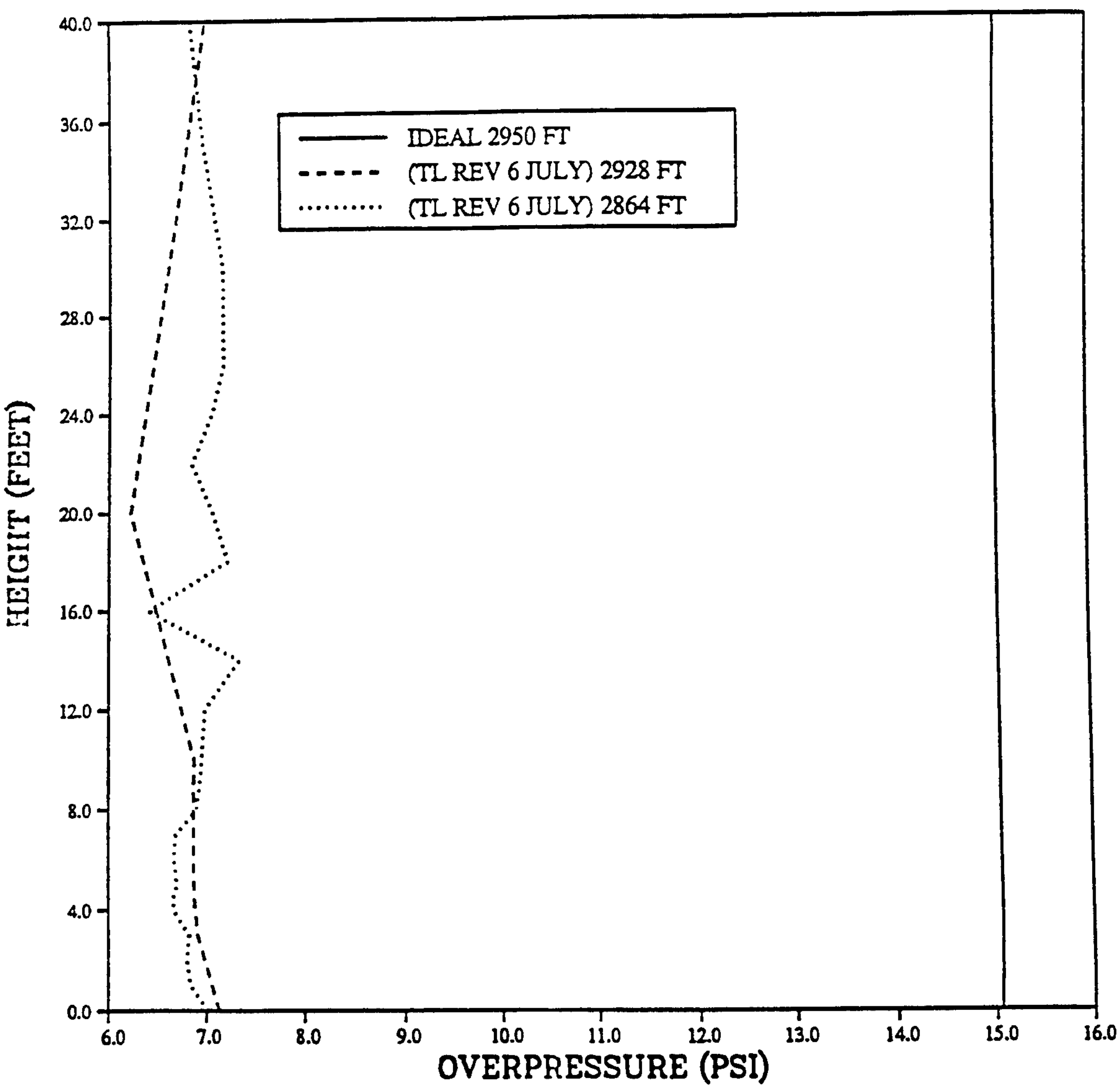
PRISCILLA DESERT
OVERPRESSURE AT 2300 FEET
VERTICAL PROFILE



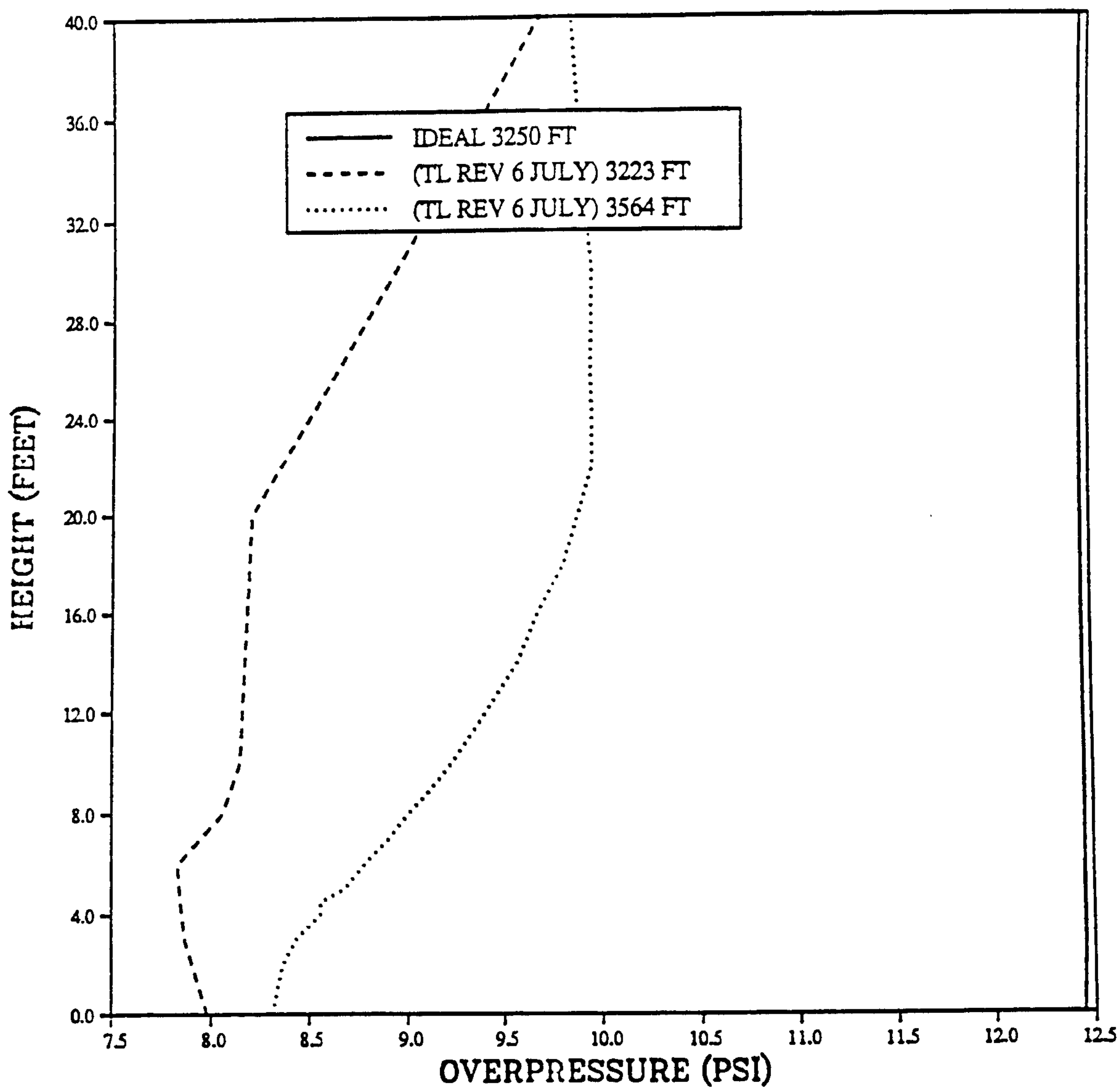
PRISCILLA DESERT
OVERPRESSURE AT 2550 FEET
VERTICAL PROFILE

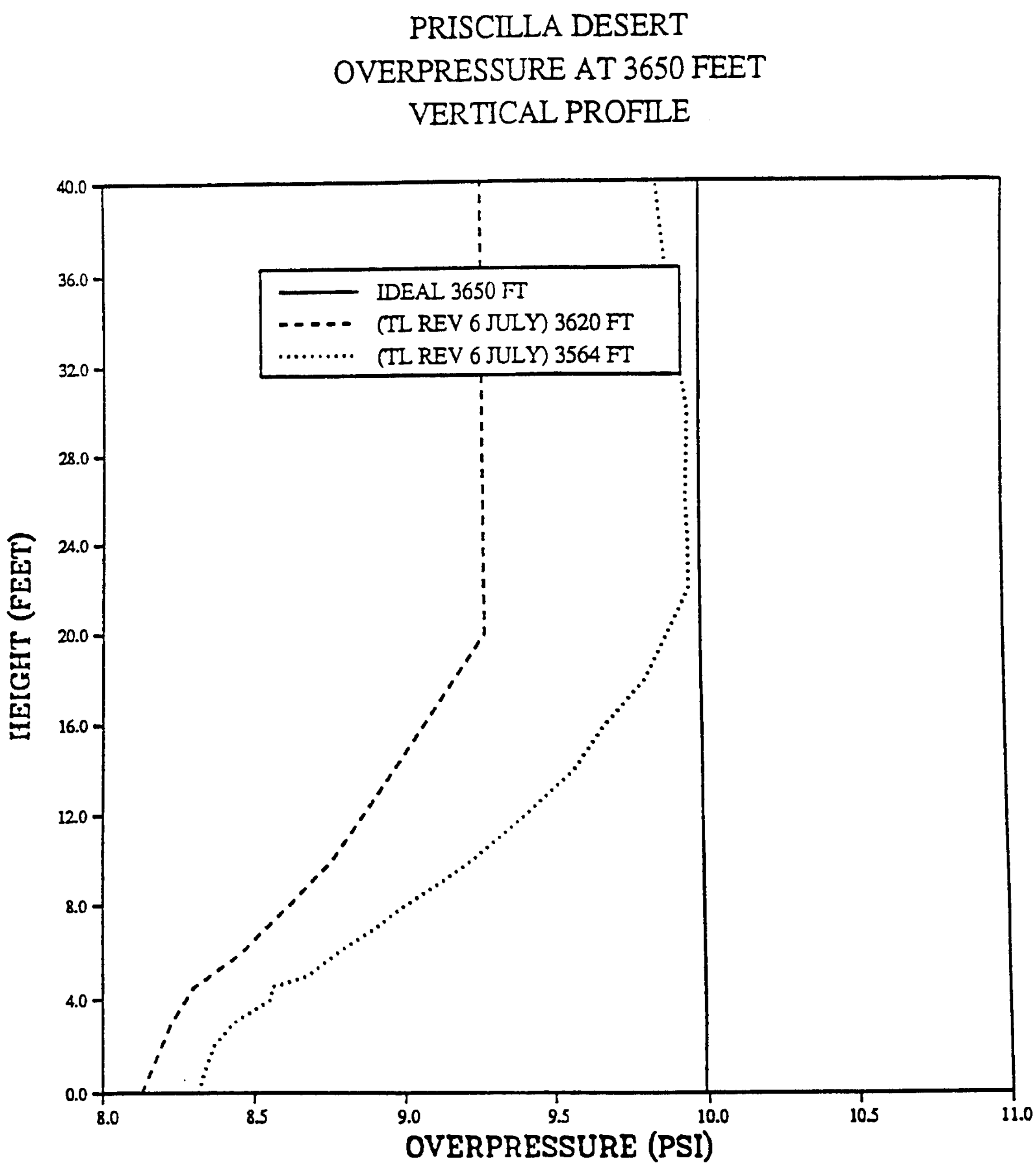


PRISCILLA DESERT
OVERPRESSURE AT 2950 FEET
VERTICAL PROFILE



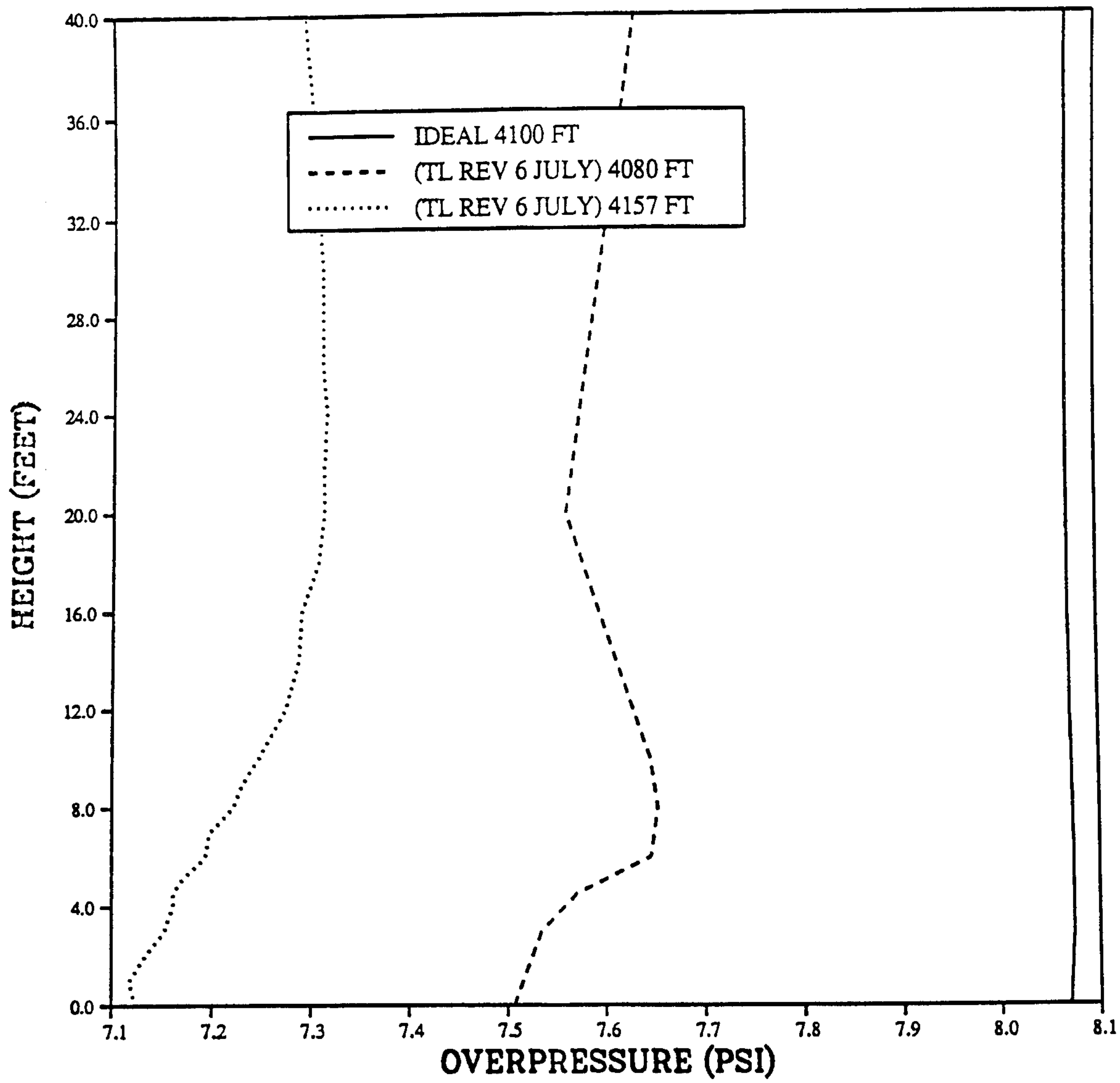
PRISCILLA DESERT
OVERPRESSURE AT 3250 FEET
VERTICAL PROFILE



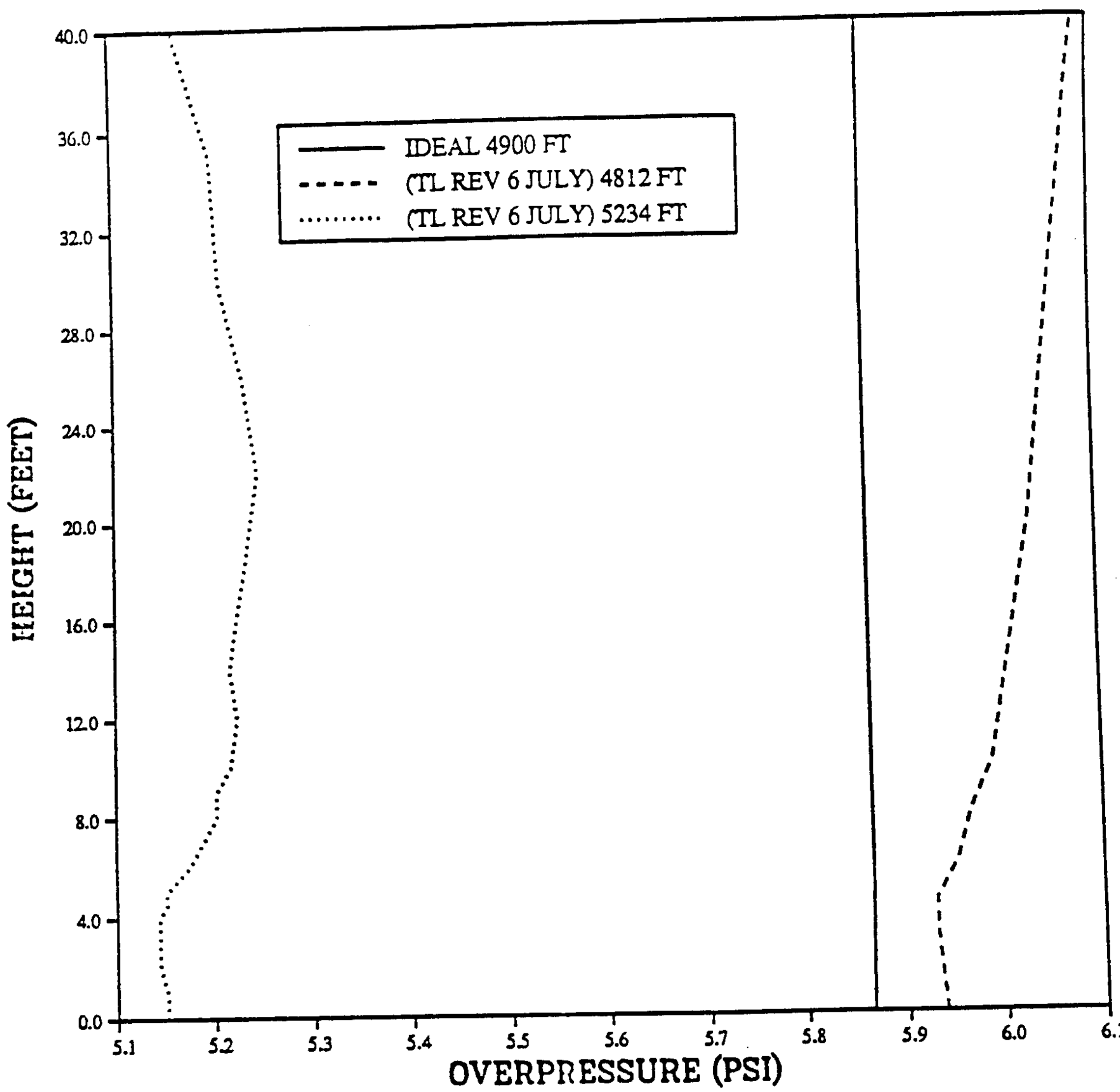


PRISCILLA DESERT
OVERPRESSURE AT 3650 FEET
VERTICAL PROFILE
IDEAL 3650 FT
(TL REV 6 JULY) 3620 FT
(TL REV 6 JULY) 3564 FT
HEIGHT (FEET)
OVERPRESSURE (PSI)
40.0
36.0
32.0
28.0
24.0
20.0
16.0
12.0
8.0
4.0
0.0
8.0
8.5
9.0
9.5
10.0
10.5
11.0

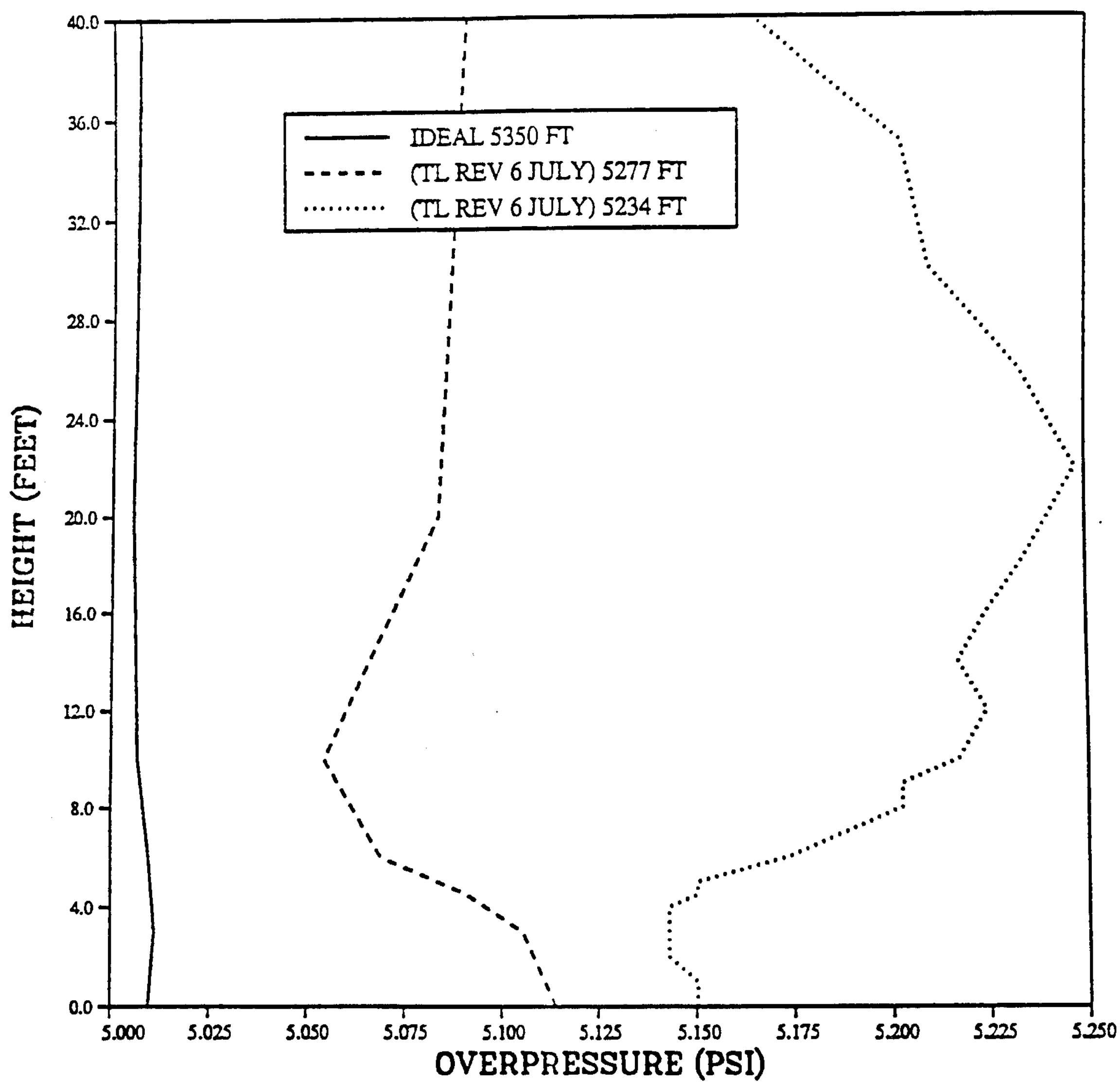
PRISCILLA DESERT
OVERPRESSURE AT 4100 FEET
VERTICAL PROFILE

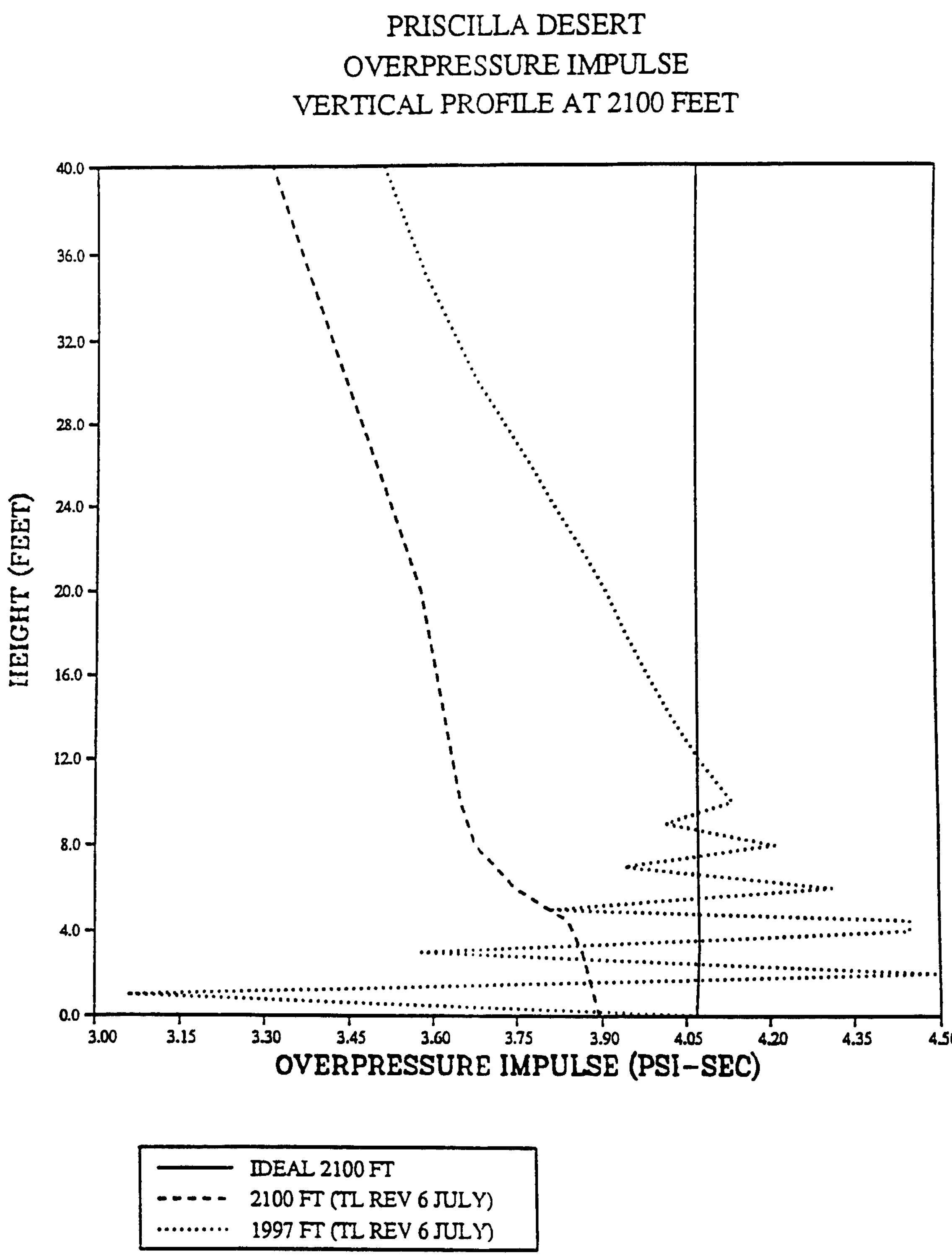


PRISCILLA DESERT
OVERPRESSURE AT 4900 FEET
VERTICAL PROFILE

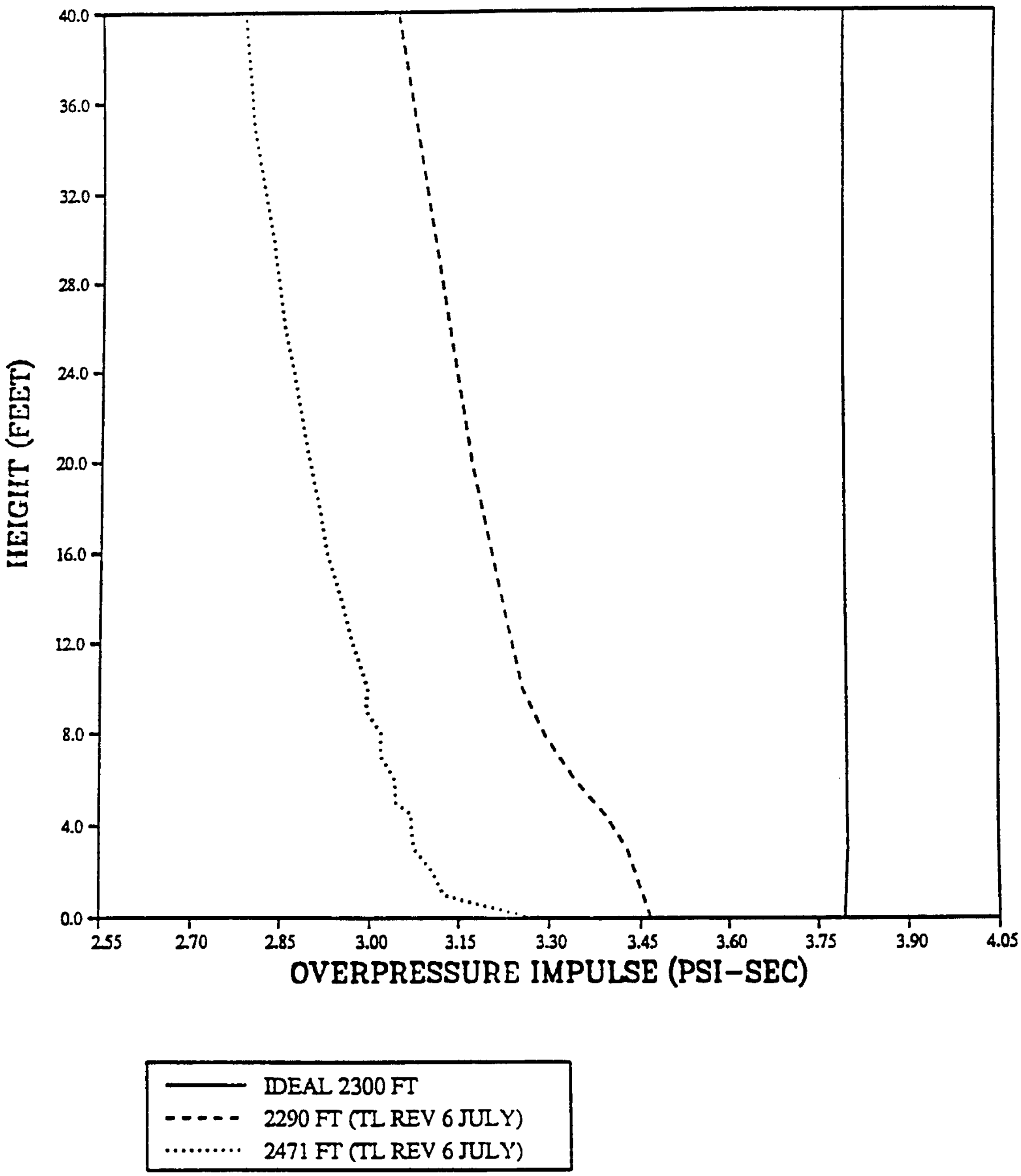


PRISCILLA DESERT
OVERPRESSURE AT 5350 FEET
VERTICAL PROFILE

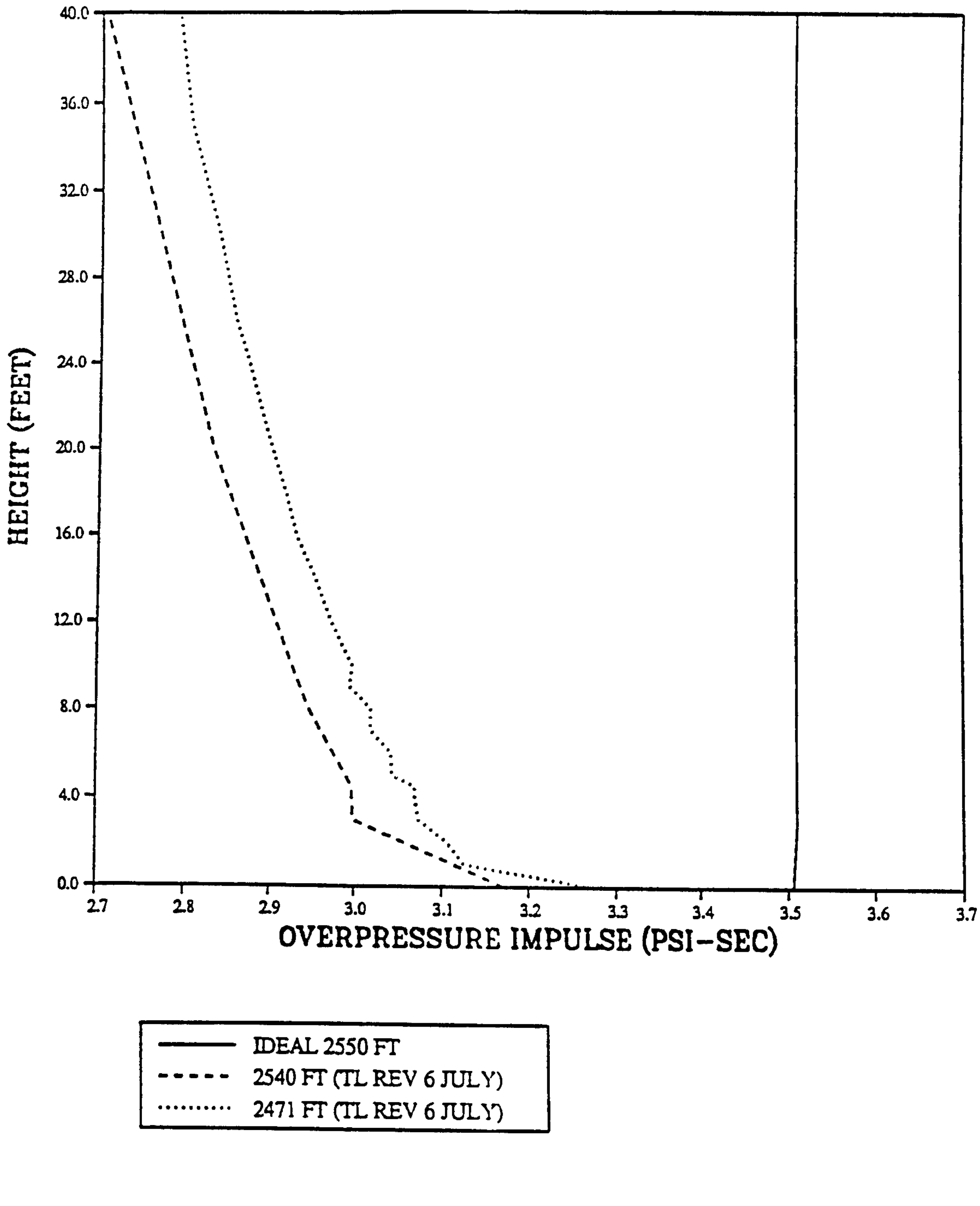



PRISCILLA DESERT
OVERPRESSURE IMPULSE
VERTICAL PROFILE AT 2100 FEET
HEIGHT (FEET)
40.0
36.0
32.0
28.0
24.0
20.0
16.0
12.0
8.0
4.0
0.0
3.00
3.15
3.30
3.45
3.60
3.75
3.90
4.05
4.20
4.35
4.50
OVERPRESSURE IMPULSE (PSI-SEC)
IDEAL 2100 FT
2100 FT (TL REV 6 JULY)
1997 FT (TL REV 6 JULY)

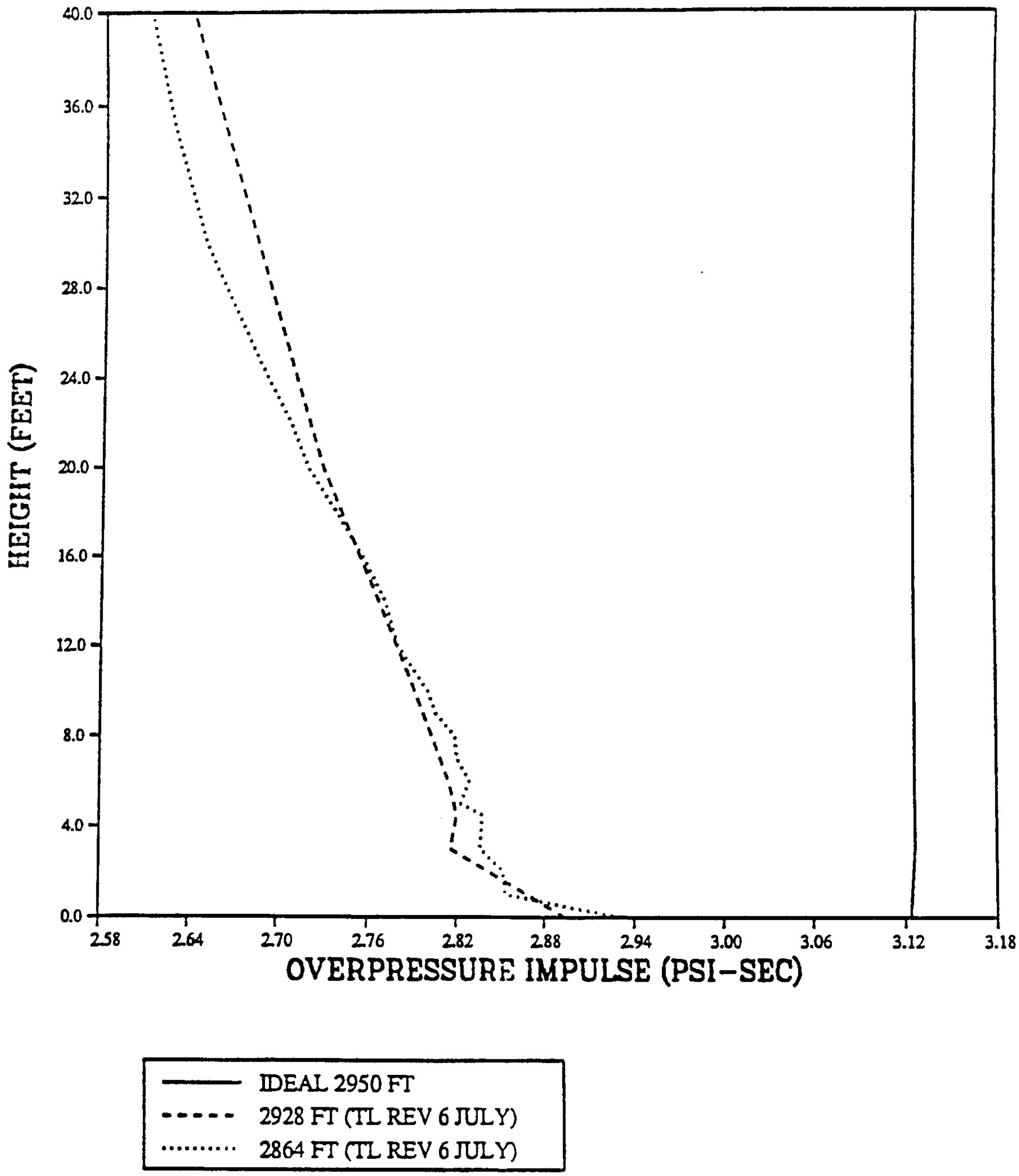
PRISCILLA DESERT
OVERPRESSURE IMPULSE
VERTICAL PROFILE AT 2300 FEET



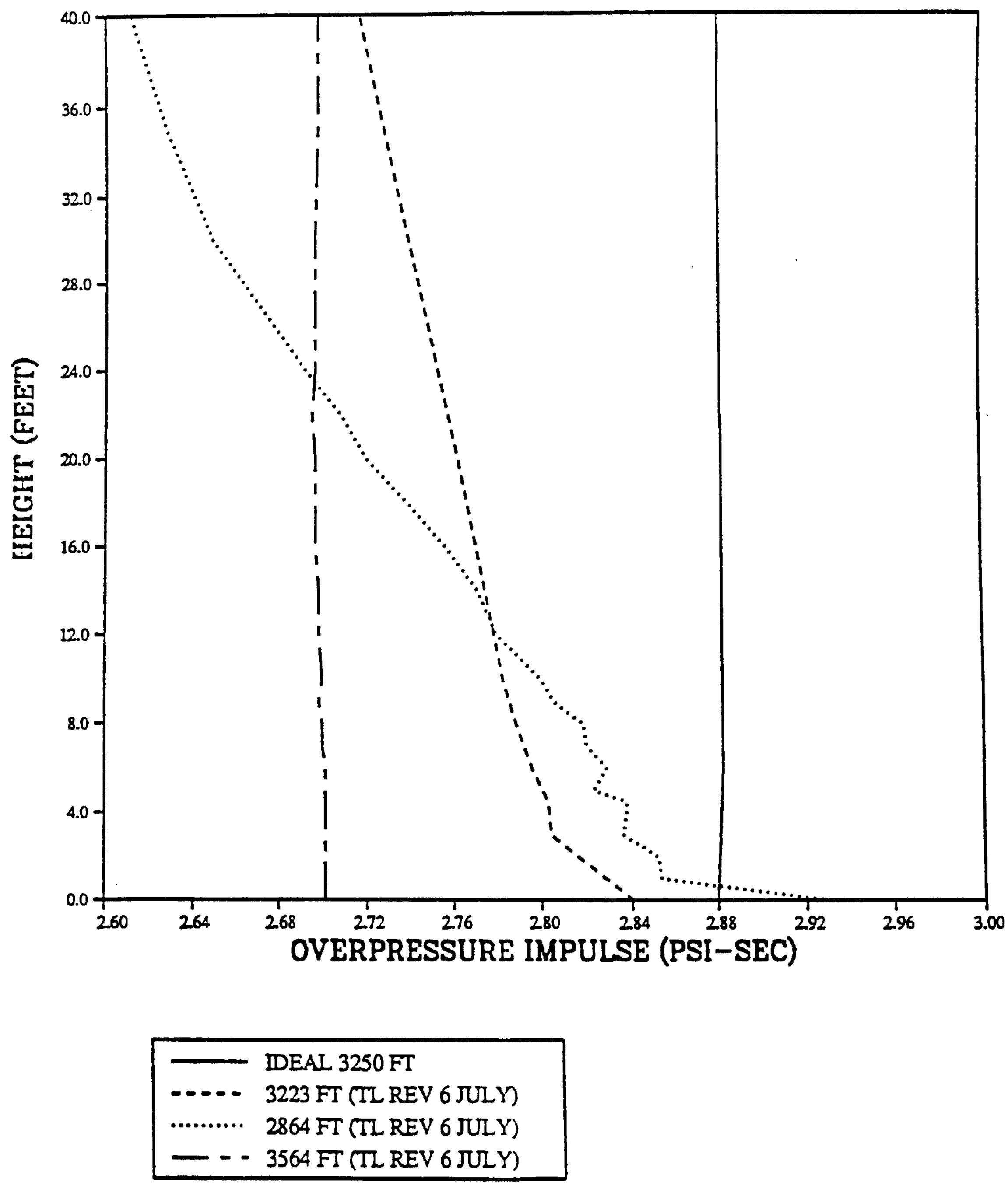
PRISCILLA DESERT
OVERPRESSURE IMPULSE
VERTICAL PROFILE AT 2550 FEET



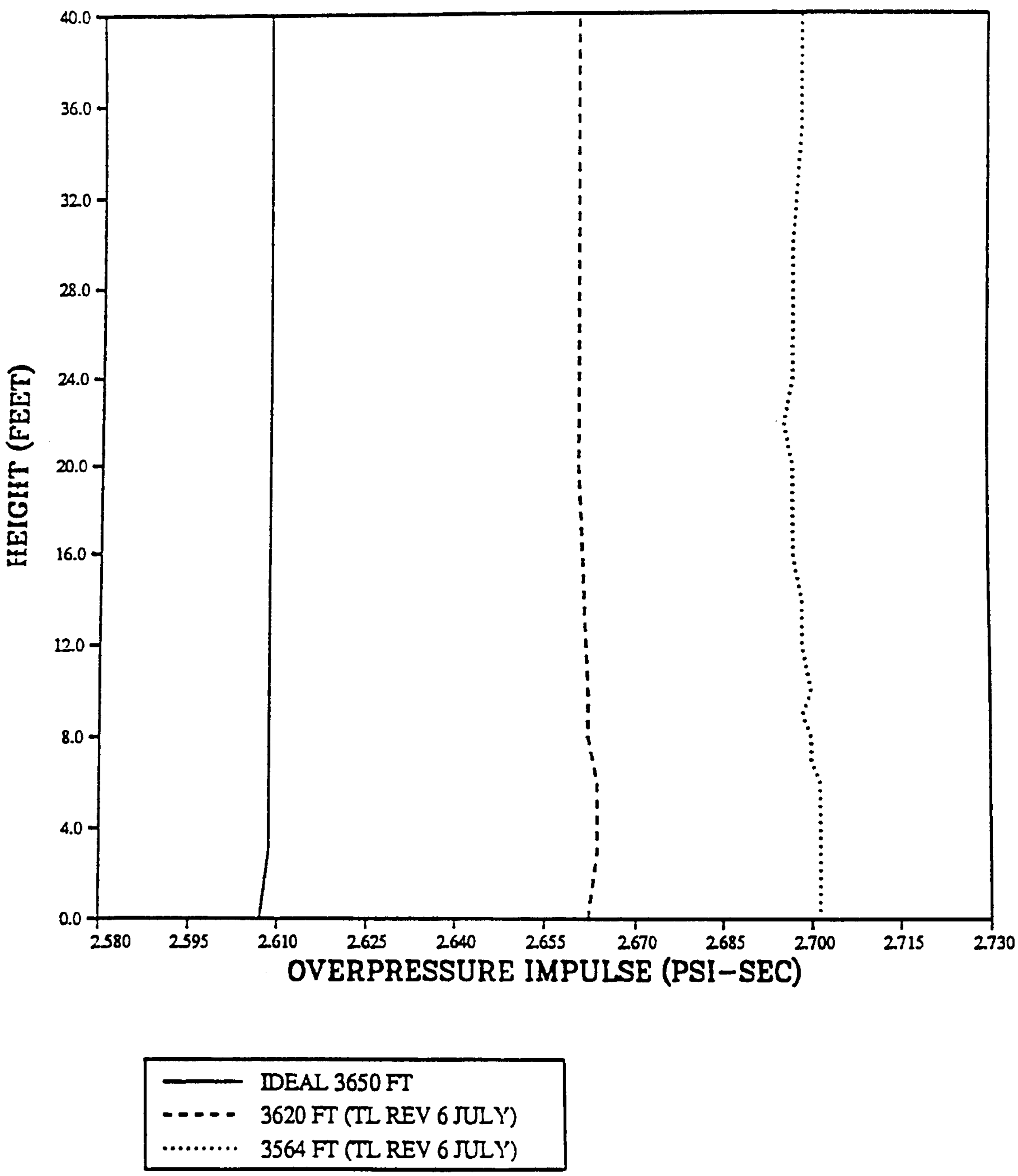
PRISCILLA DESERT
OVERPRESSURE IMPULSE
VERTICAL PROFILE AT 2950 FEET



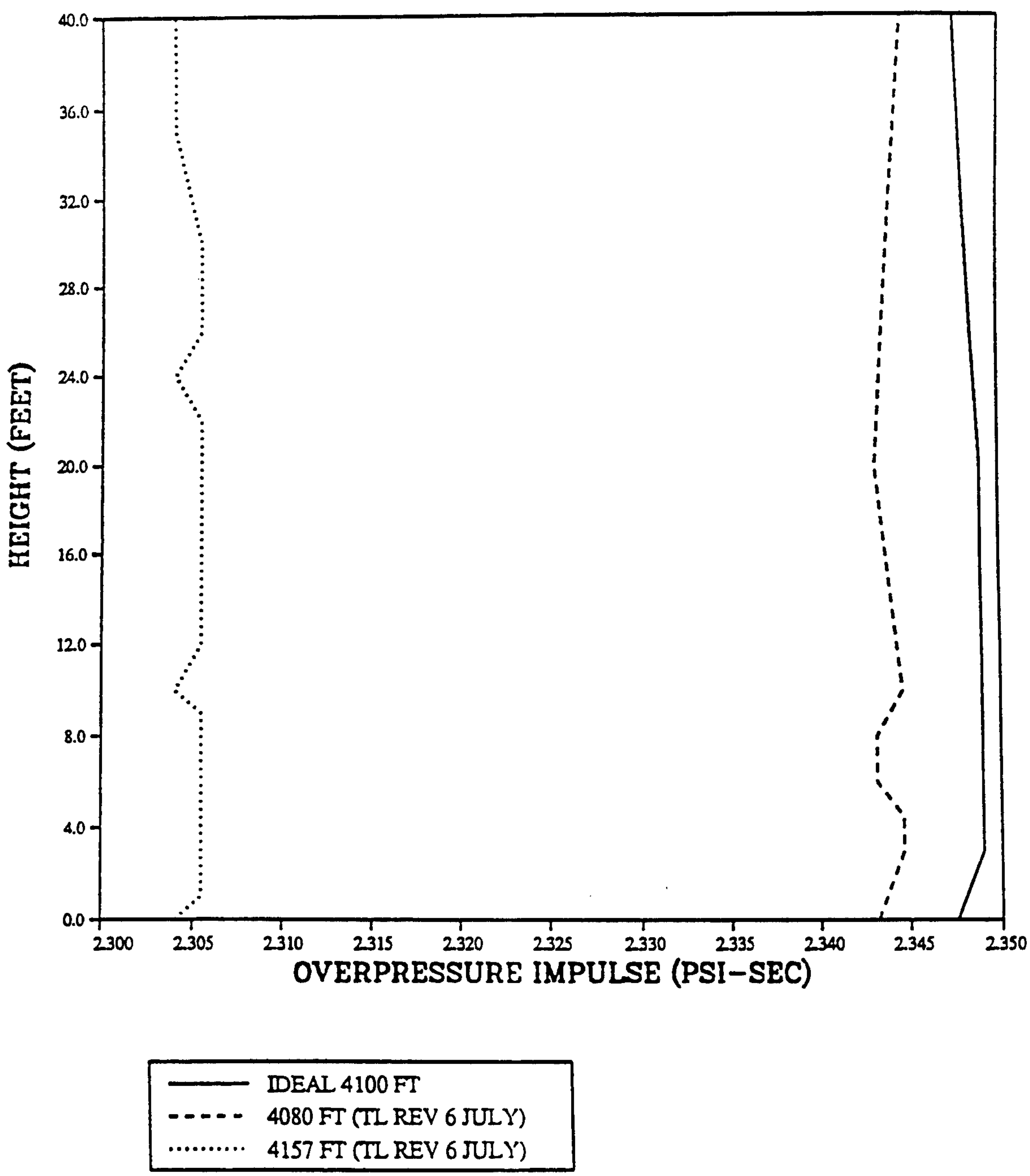
PRISCILLA DESERT
OVERPRESSURE IMPULSE
VERTICAL PROFILE AT 3250 FEET

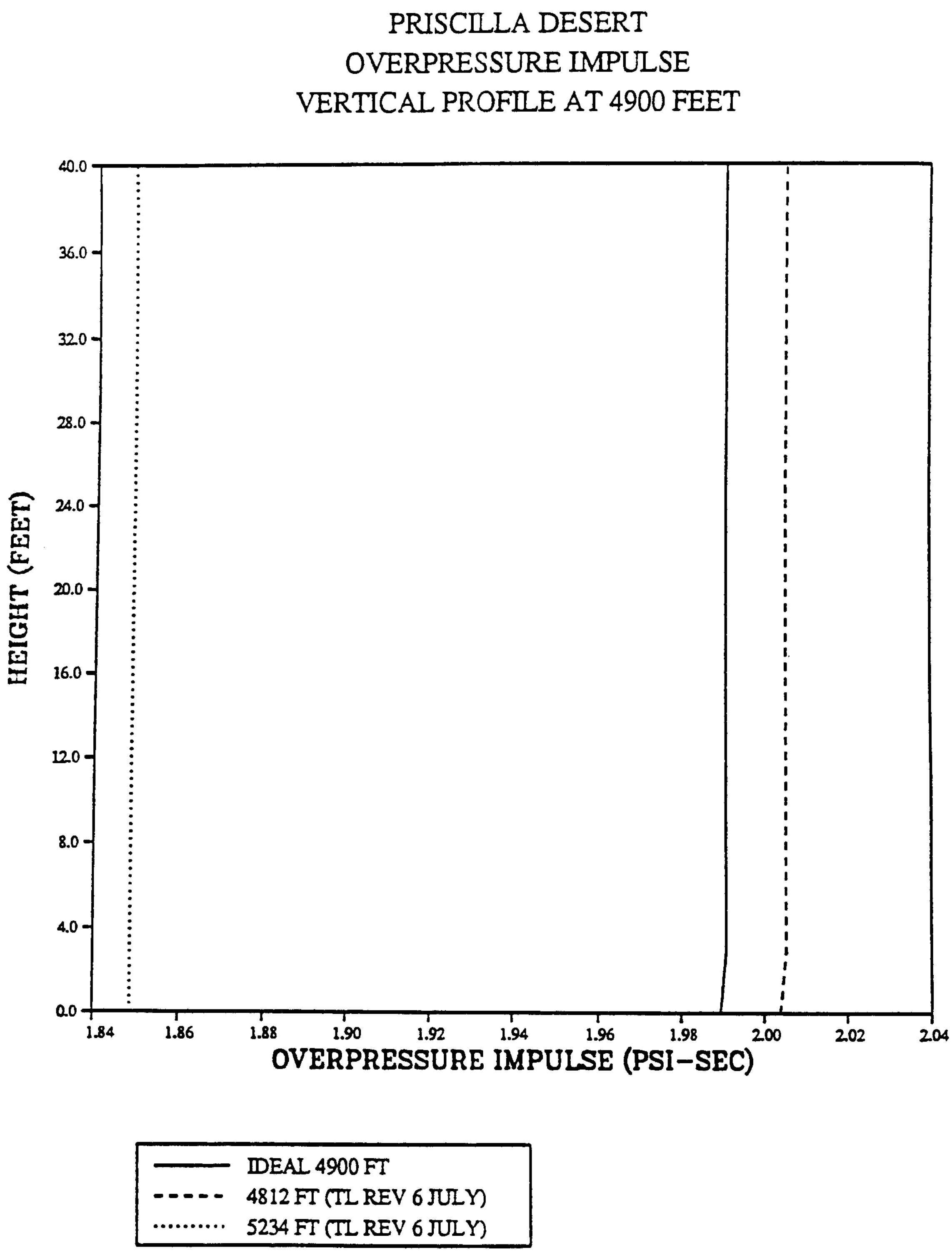


PRISCILLA DESERT
OVERPRESSURE IMPULSE
VERTICAL PROFILE AT 3650 FEET



PRISCILLA DESERT
OVERPRESSURE IMPULSE
VERTICAL PROFILE AT 4100 FEET

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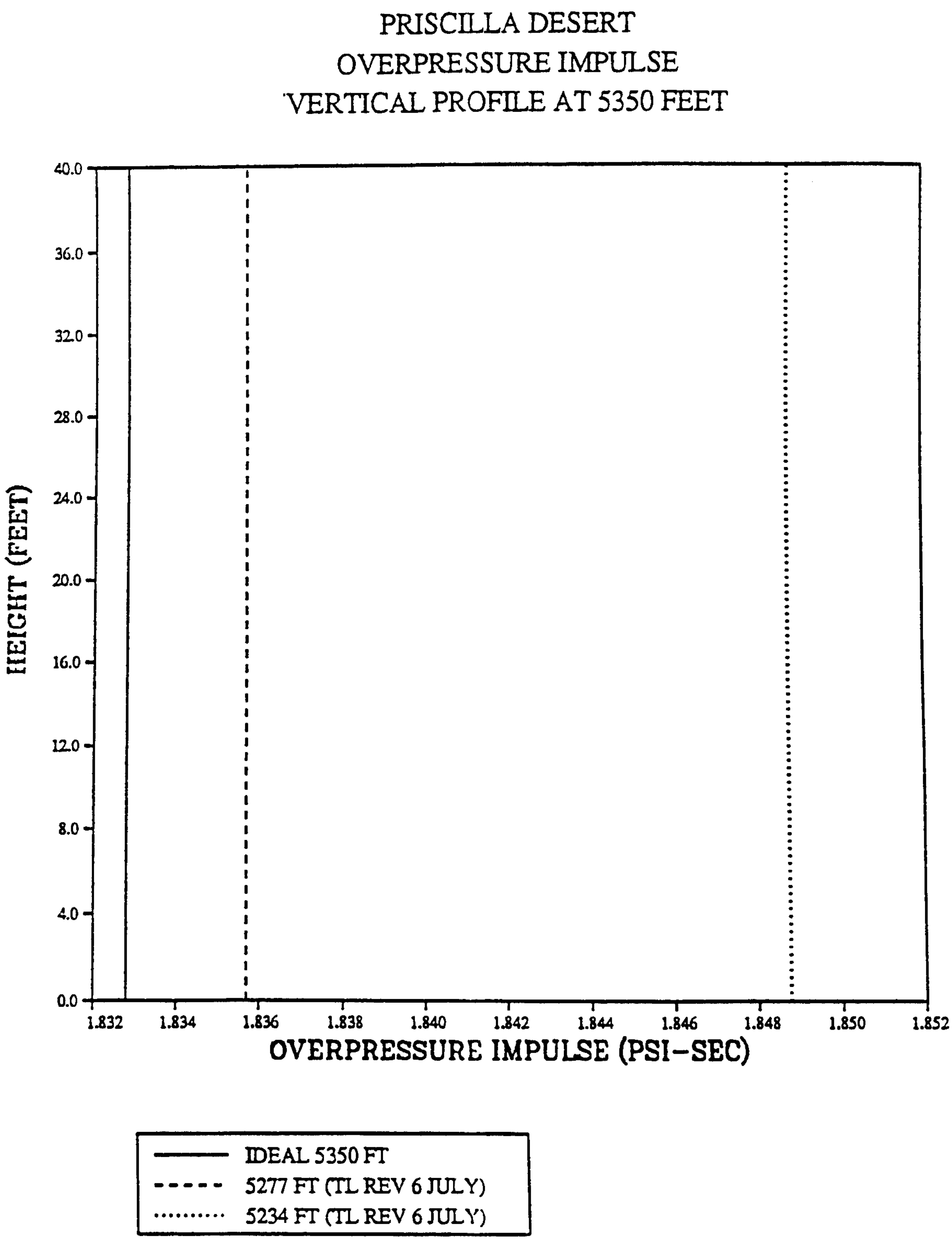
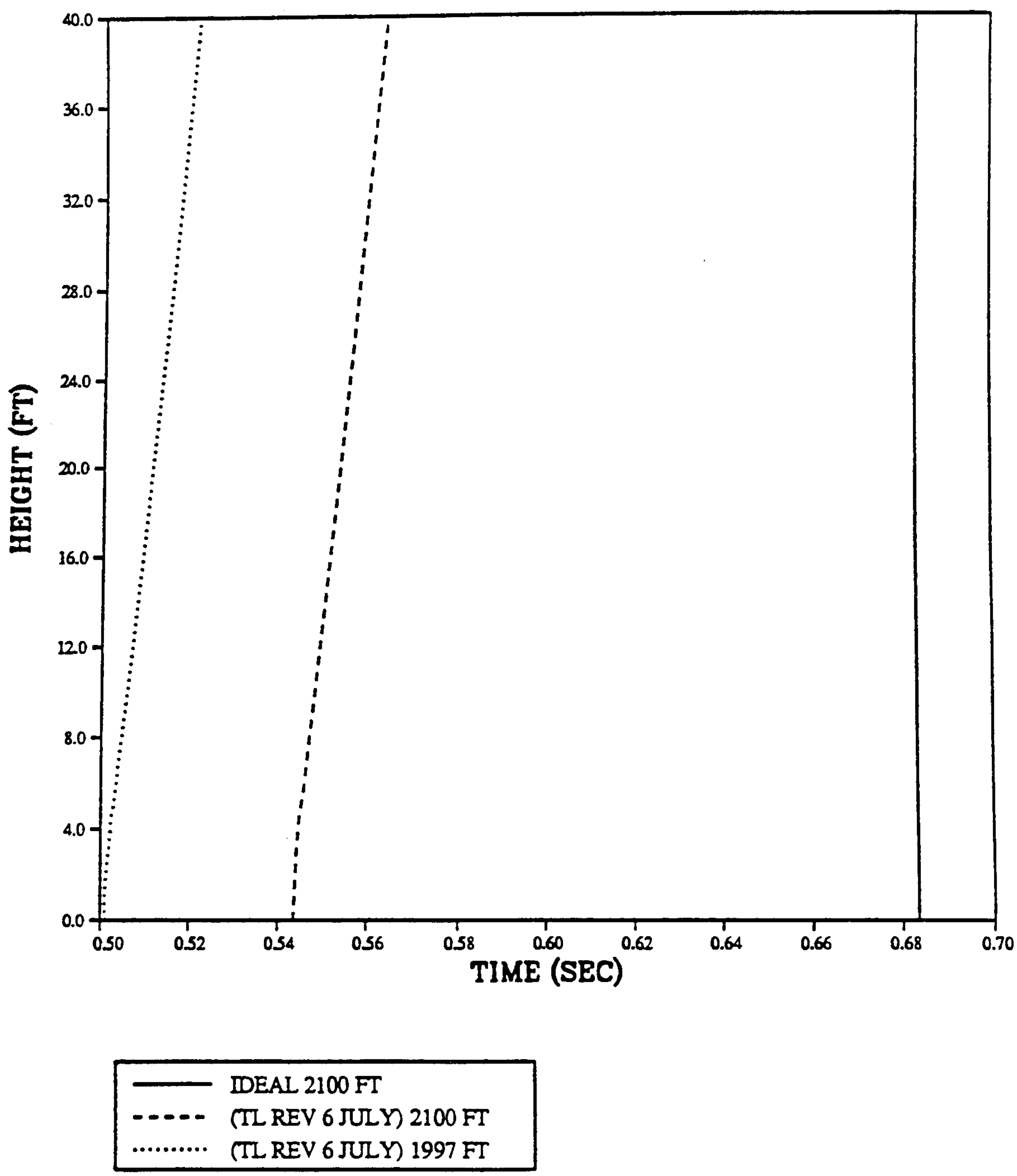
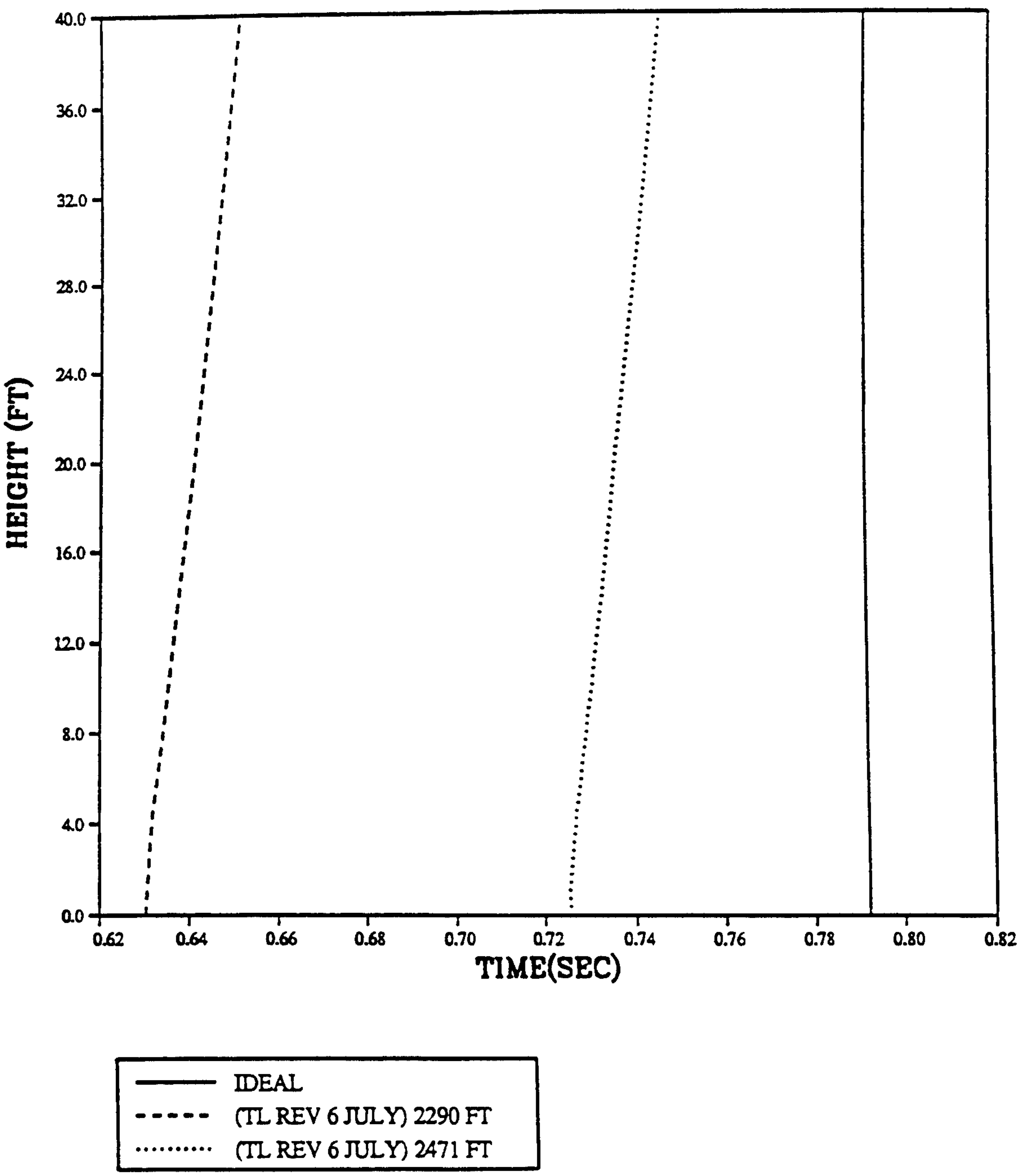
OVERPRESSURE IMPULSE
VERTICAL PROFILE AT 4900 FEET
HEIGHT (FEET)
40.0
36.0
32.0
28.0
24.0
20.0
16.0
12.0
8.0
4.0
0.0
1.84
1.86
1.88
1.90
1.92
1.94
1.96
1.98
2.00
2.02
2.04
OVERPRESSURE IMPULSE (PSI-SEC)
IDEAL 4900 FT
4812 FT (TL REV 6 JULY)
5234 FT (TL REV 6 JULY)


PRISCILLA DESERT
OVERPRESSURE IMPULSE
VERTICAL PROFILE AT 5350 FEET
HEIGHT (FEET)
40.0
36.0
32.0
28.0
24.0
20.0
16.0
12.0
8.0
4.0
0.0
1.832
1.834
1.836
1.838
1.840
1.842
1.844
1.846
1.848
1.850
1.852
OVERPRESSURE IMPULSE (PSI-SEC)
IDEAL 5350 FT
5277 FT (TL REV 6 JULY)
5234 FT (TL REV 6 JULY)

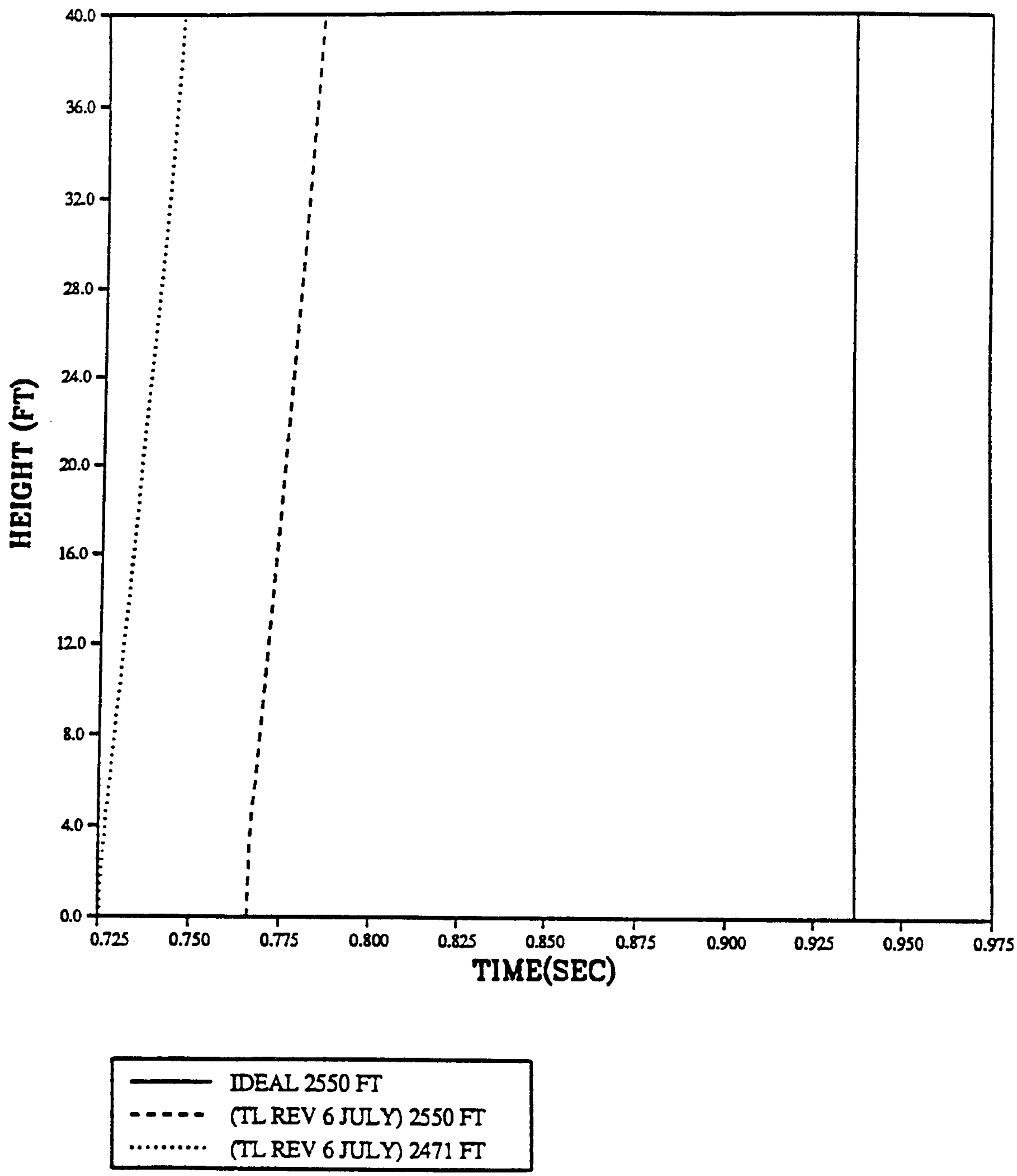
PRISCILLA
ARRIVAL TIME
VERTICAL PROFILE AT 2100 FEET



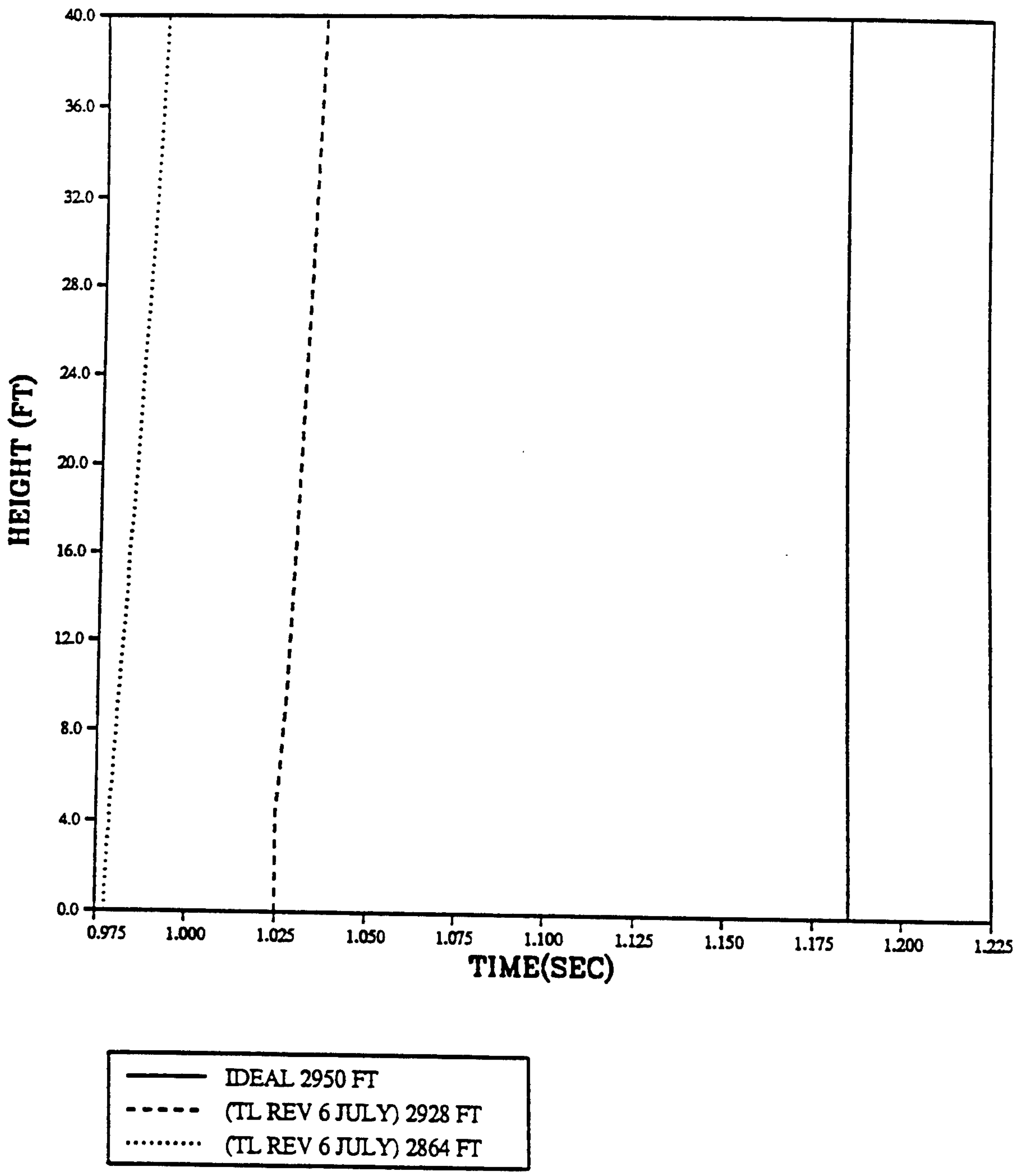
PRISCILLA
ARRIVAL TIME
VERTICAL PROFILE AT 2300 FEET



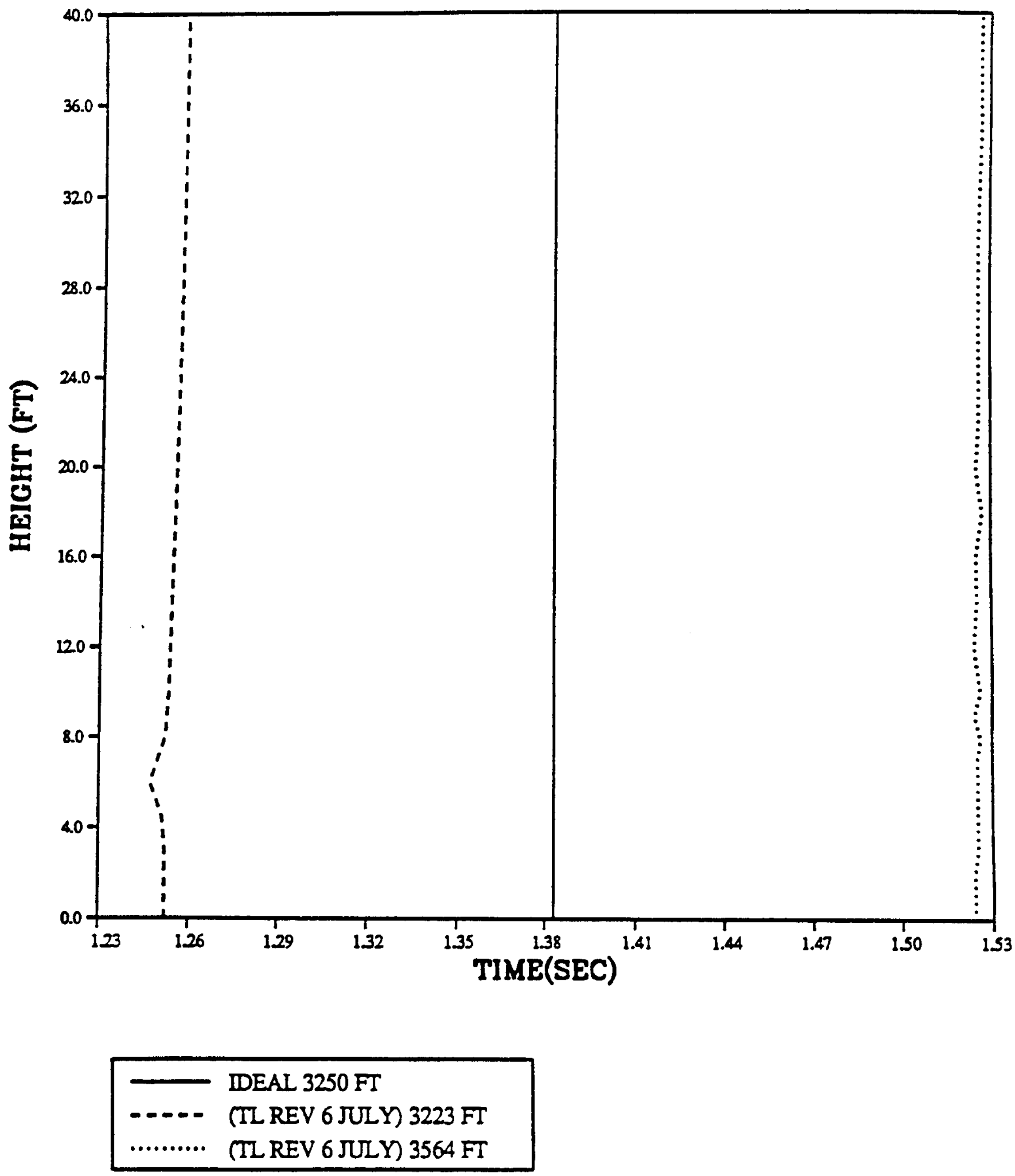
PRISCILLA
ARRIVAL TIME
VERTICAL PROFILE AT 2550 FEET



PRISCILLA
ARRIVAL TIME
VERTICAL PROFILE AT 2950 FEET



PRISCILLA
ARRIVAL TIME
VERTICAL PROFILE AT 3250 FEET



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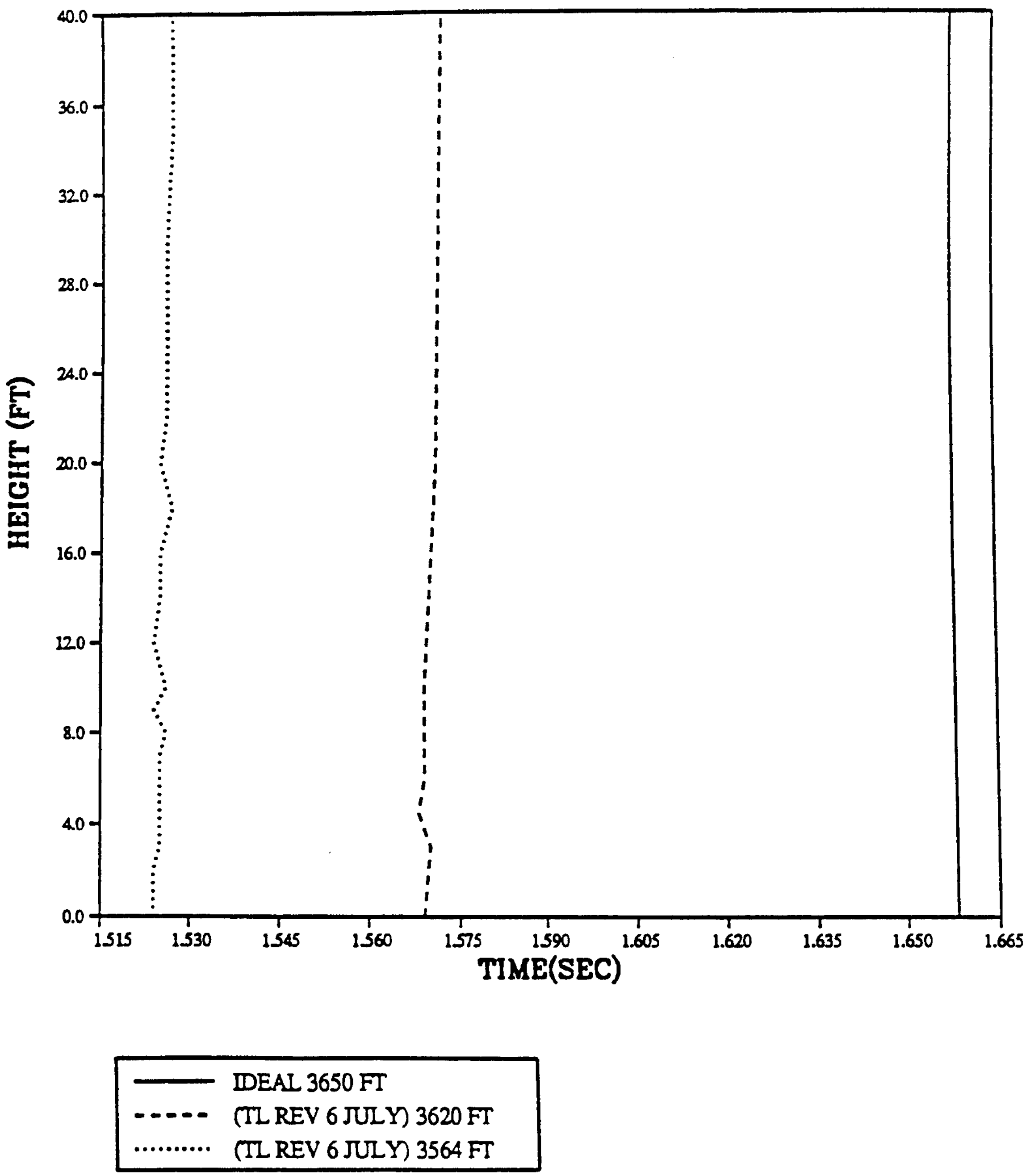
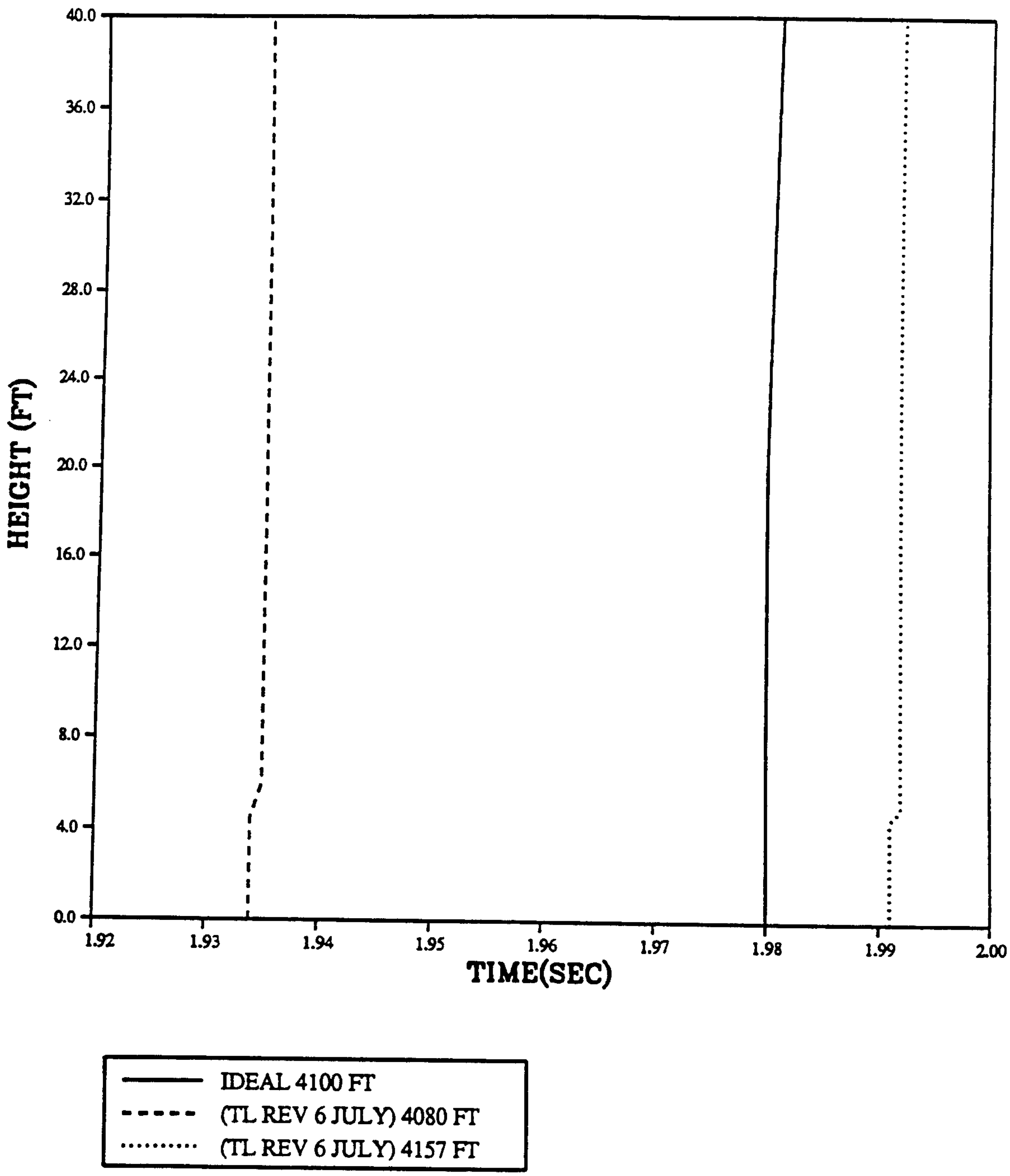
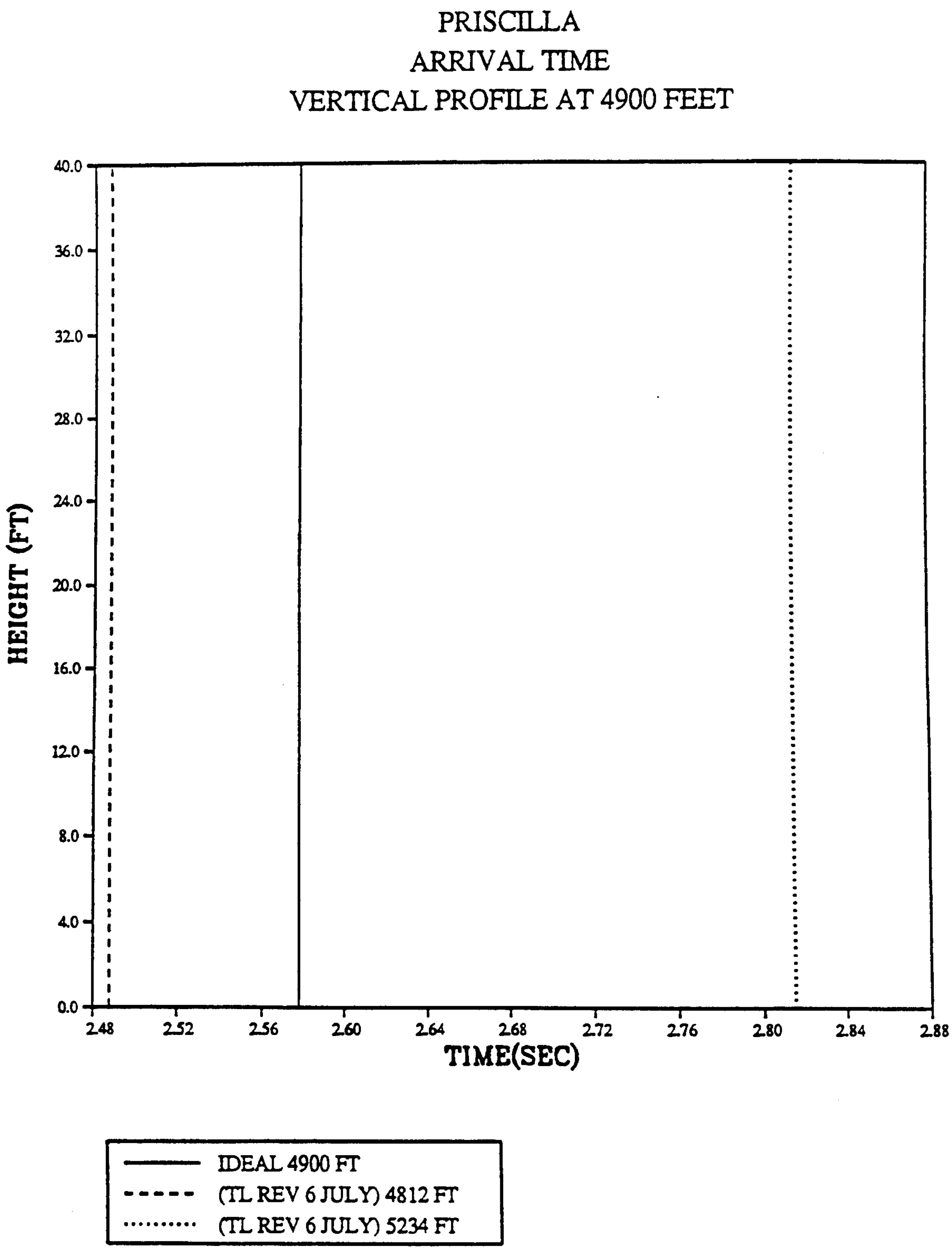
ARRIVAL TIME
VERTICAL PROFILE AT 3650 FEET

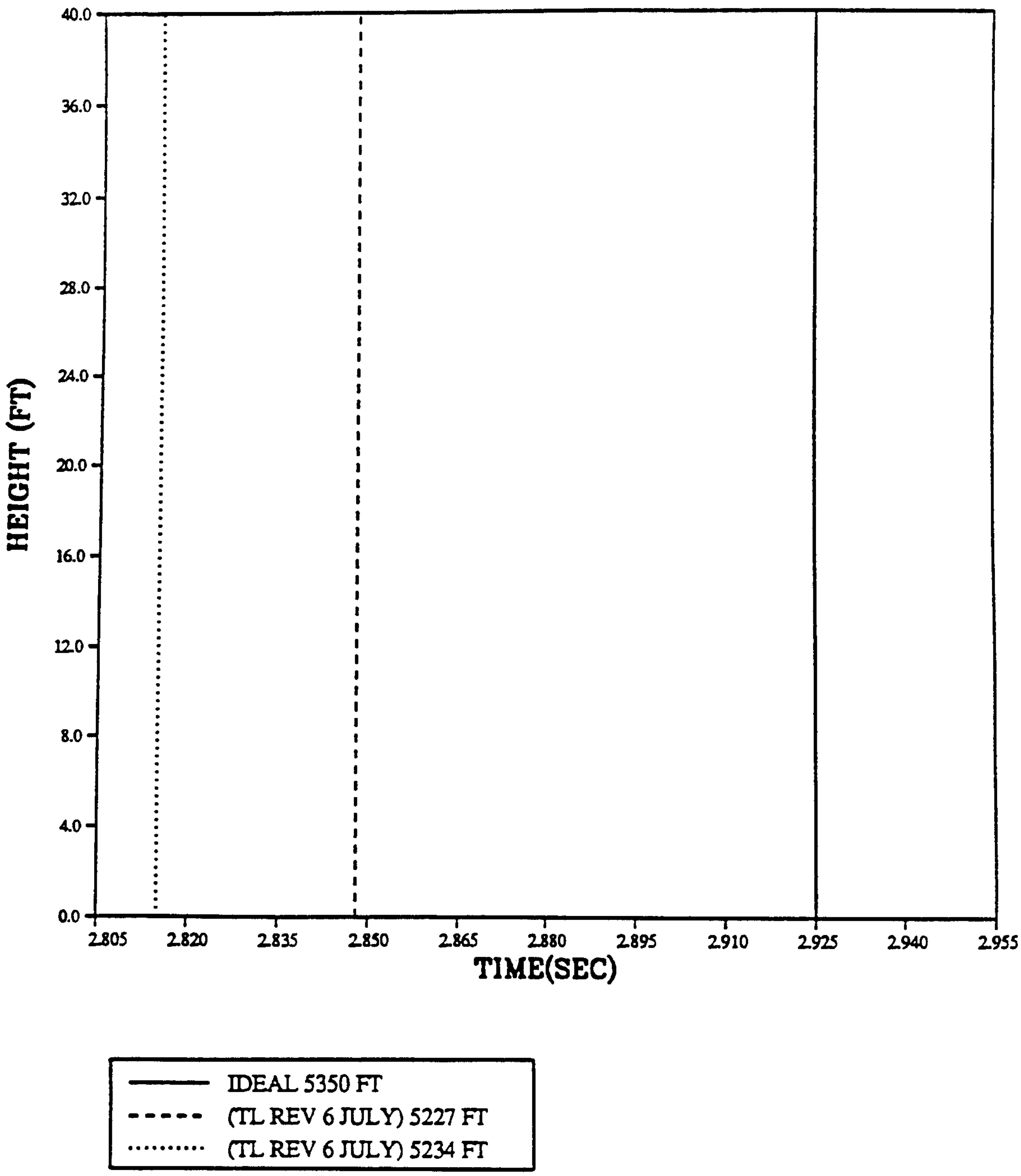


PRISCILLA
ARRIVAL TIME
VERTICAL PROFILE AT 4100 FEET

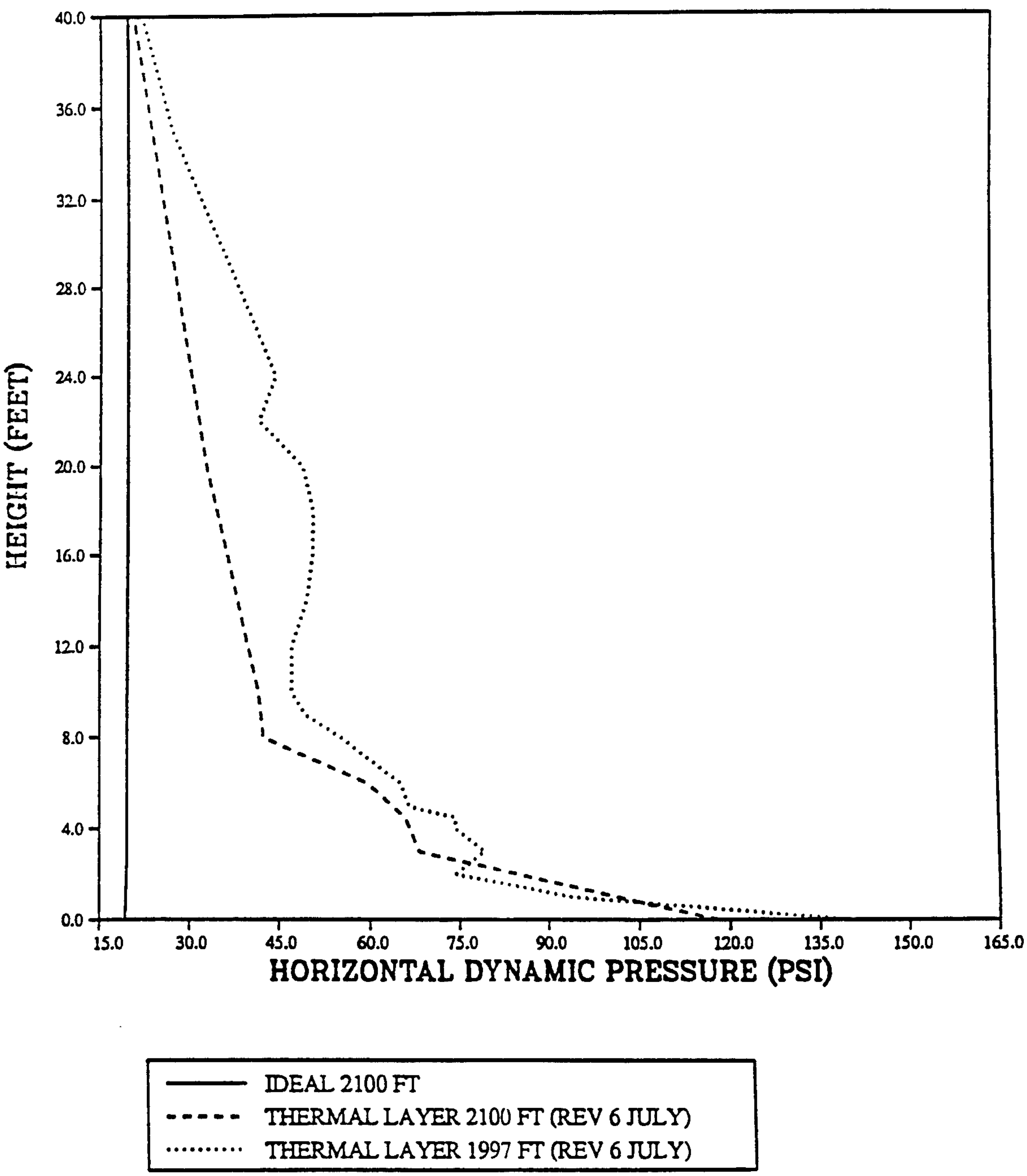



PRISCILLA
ARRIVAL TIME
VERTICAL PROFILE AT 4900 FEET
HEIGHT (FT)
40.0
36.0
32.0
28.0
24.0
20.0
16.0
12.0
8.0
4.0
0.0
2.48
2.52
2.56
2.60
2.64
2.68
2.72
2.76
2.80
2.84
2.88
TIME(SEC)
IDEAL 4900 FT
(TL REV 6 JULY) 4812 FT
(TL REV 6 JULY) 5234 FT

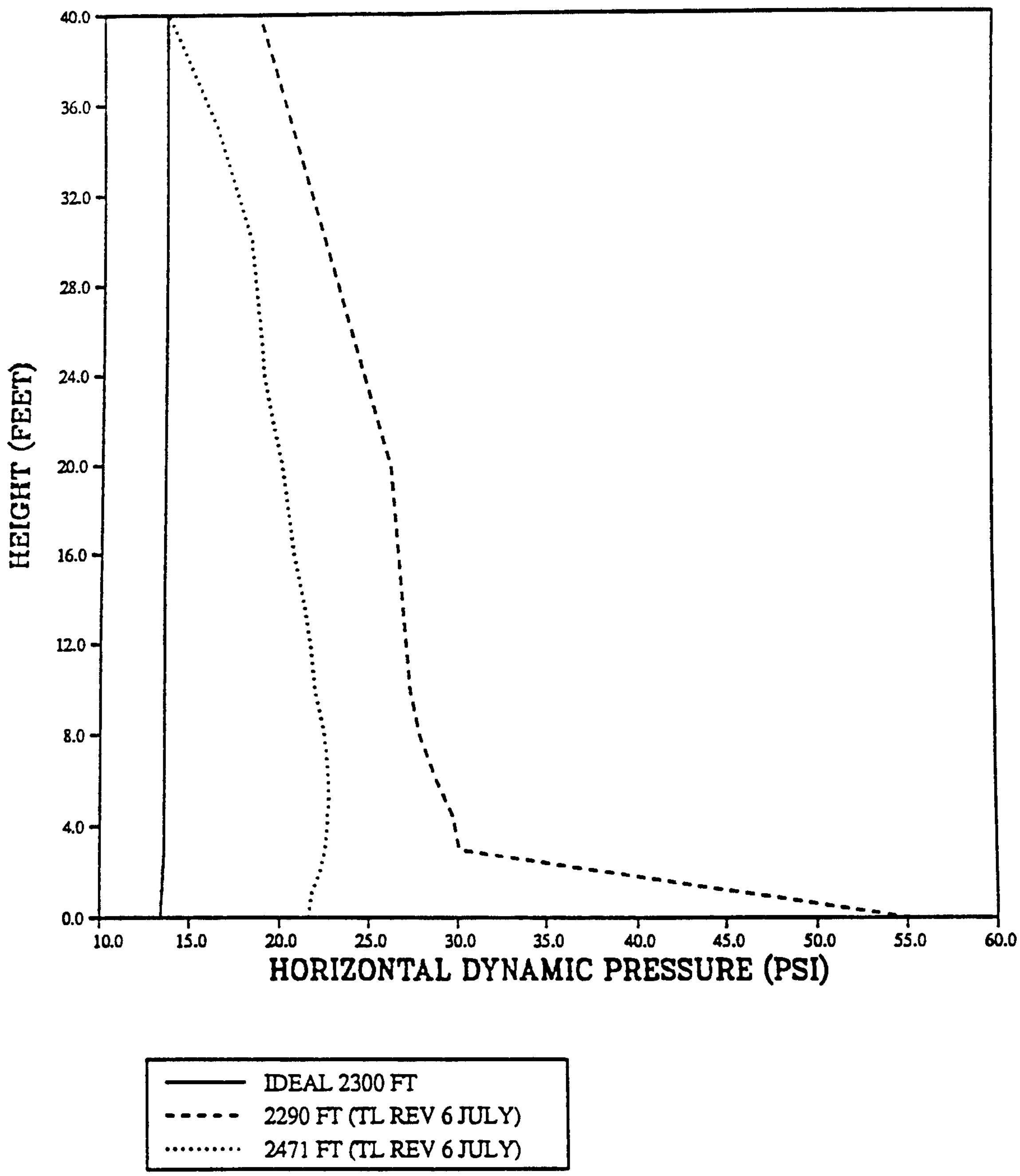
PRISCILLA
ARRIVAL TIME
VERTICAL PROFILE AT 5350 FEET



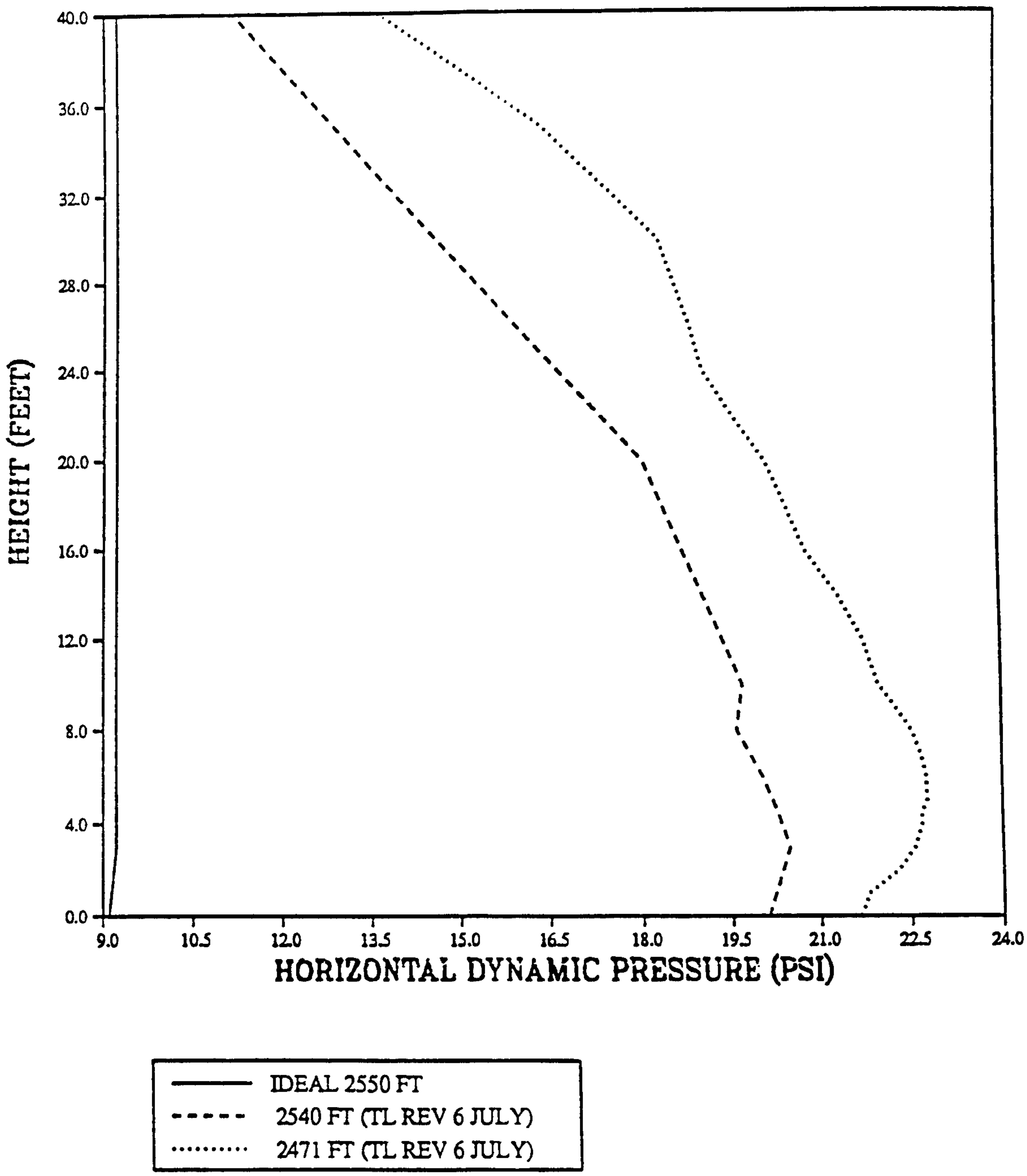
PRISCILLA DESERT
HORIZONTAL DYNAMIC PRESSURE PEAKS
VERTICAL PROFILE AT 2100 FEET



PRISCILLA DESERT
HORIZONTAL DYNAMIC PRESSURE PEAKS
VERTICAL PROFILE AT 2300 FEET



PRISCILLA DESERT
HORIZONTAL DYNAMIC PRESSURE PEAKS
VERTICAL PROFILE AT 2550 FEET



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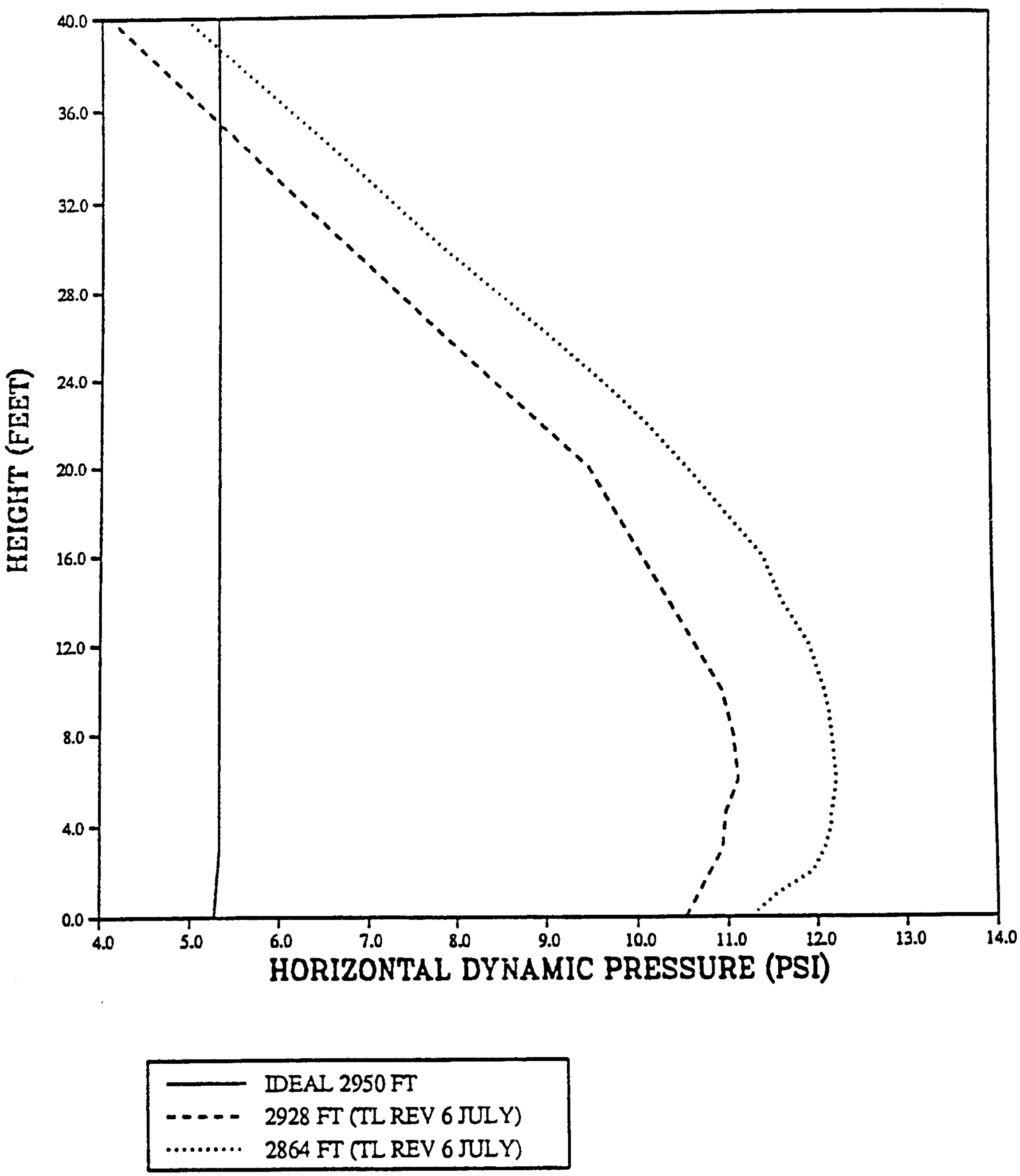
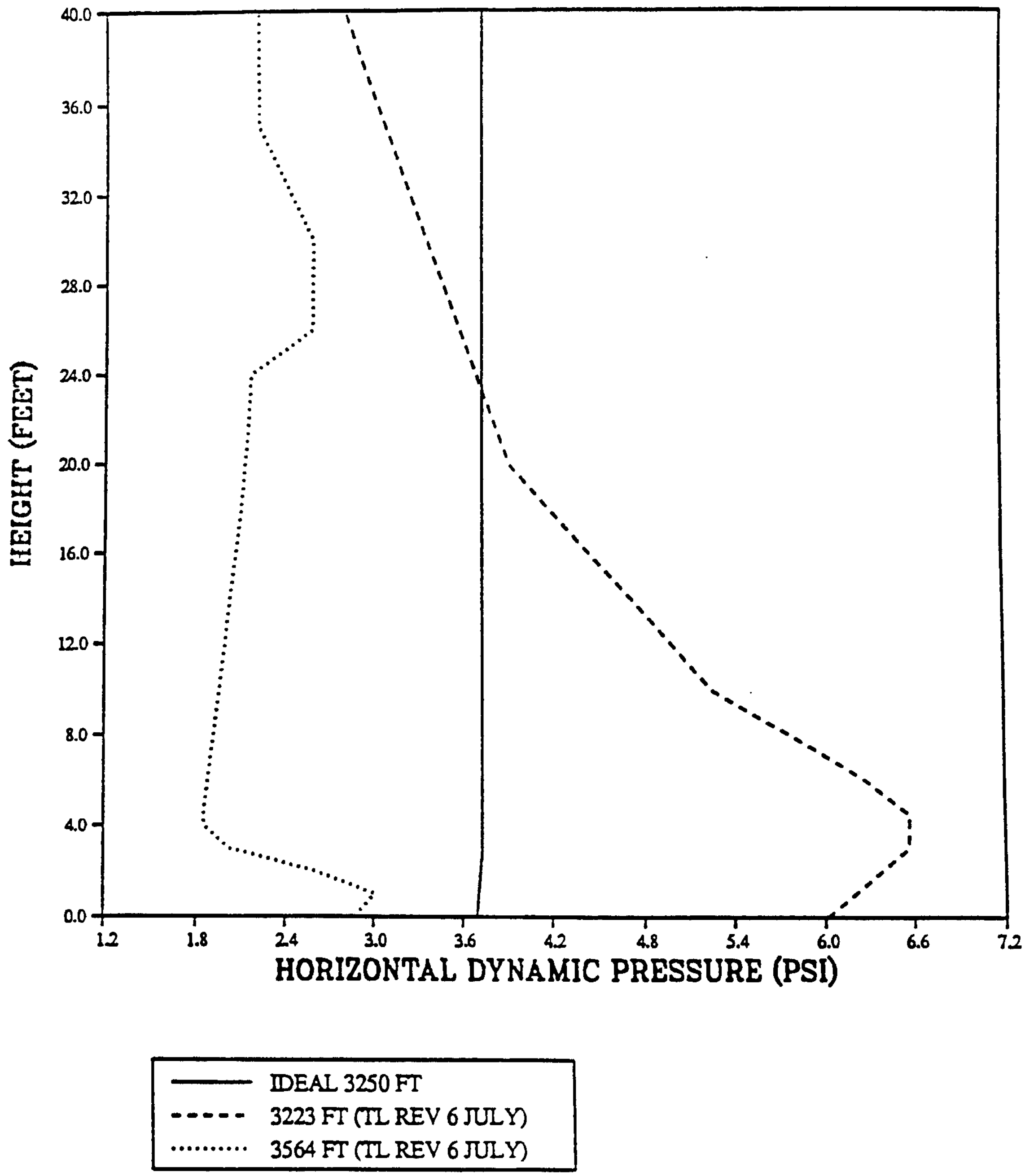
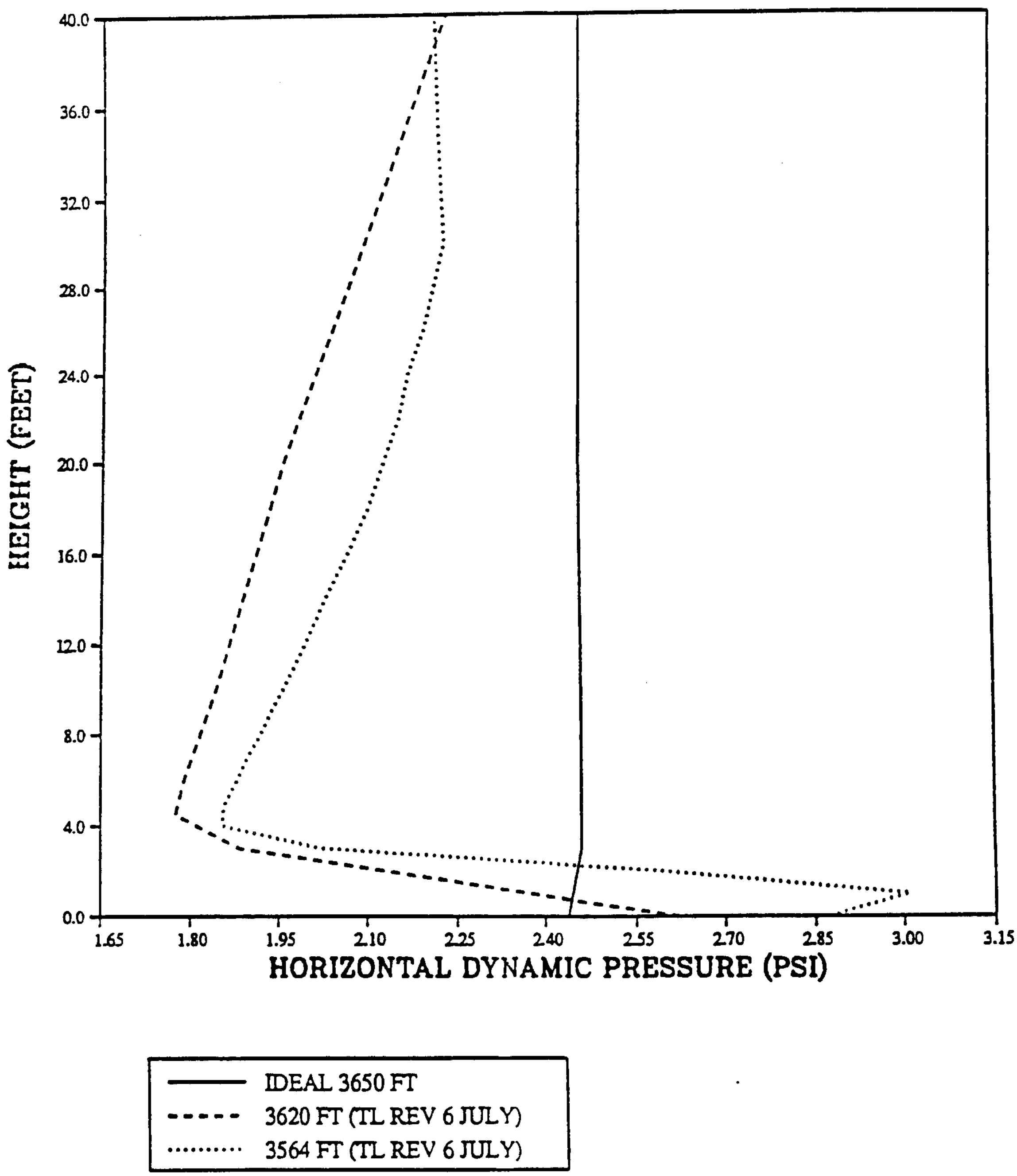
HORIZONTAL DYNAMIC PRESSURE PEAKS
VERTICAL PROFILE AT 2950 FEET

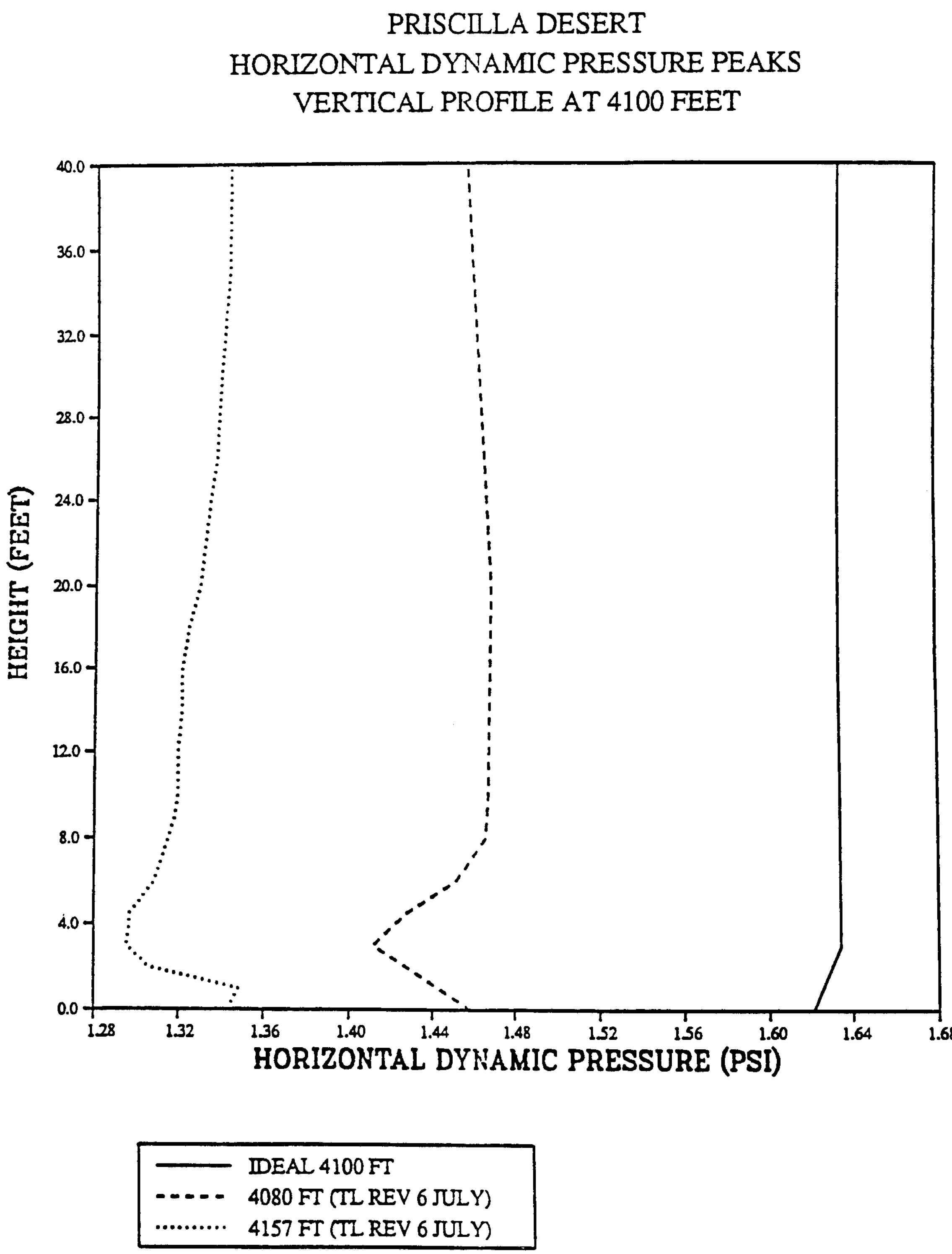


PRISCILLA DESERT
HORIZONTAL DYNAMIC PRESSURE PEAKS
VERTICAL PROFILE AT 3250 FEET

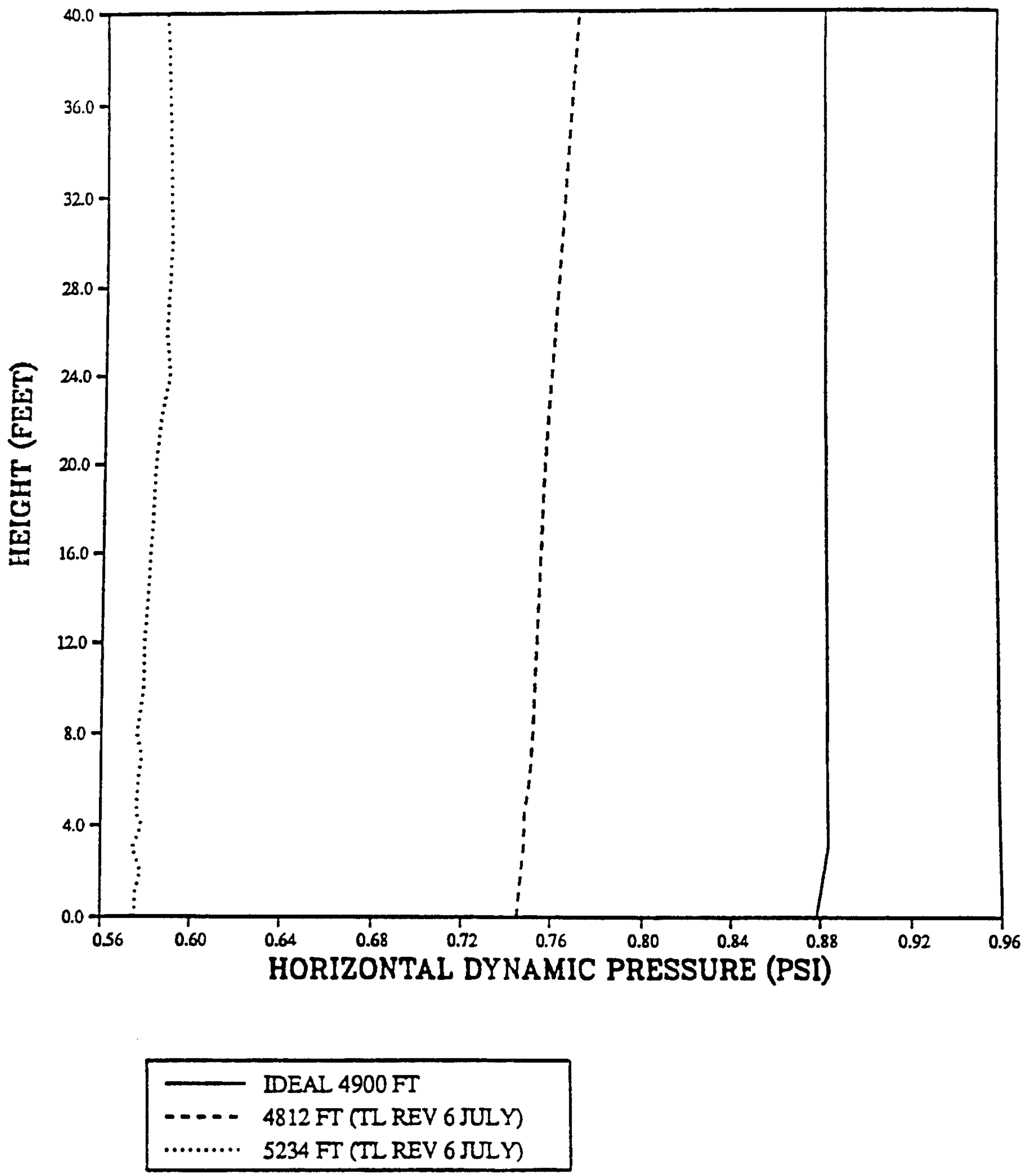


PRISCILLA DESERT
HORIZONTAL DYNAMIC PRESSURE PEAKS
VERTICAL PROFILE AT 3650 FEET

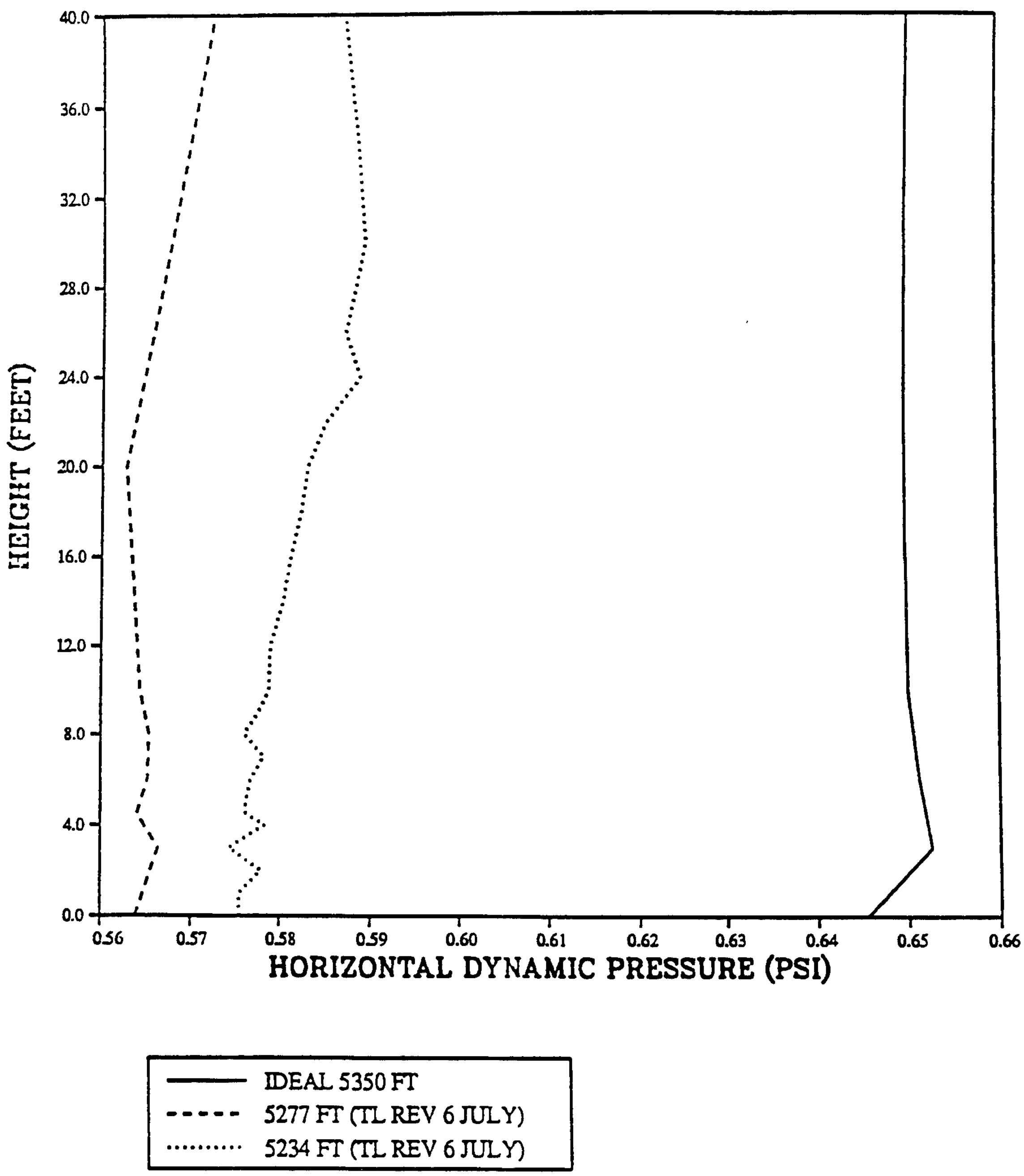



PRISCILLA DESERT
HORIZONTAL DYNAMIC PRESSURE PEAKS
VERTICAL PROFILE AT 4100 FEET
HEIGHT (FEET)
40.0
36.0
32.0
28.0
24.0
20.0
16.0
12.0
8.0
4.0
0.0
1.28
1.32
1.36
1.40
1.44
1.48
1.52
1.56
1.60
1.64
1.68
HORIZONTAL DYNAMIC PRESSURE (PSI)
IDEAL 4100 FT
4080 FT (TL REV 6 JULY)
4157 FT (TL REV 6 JULY)

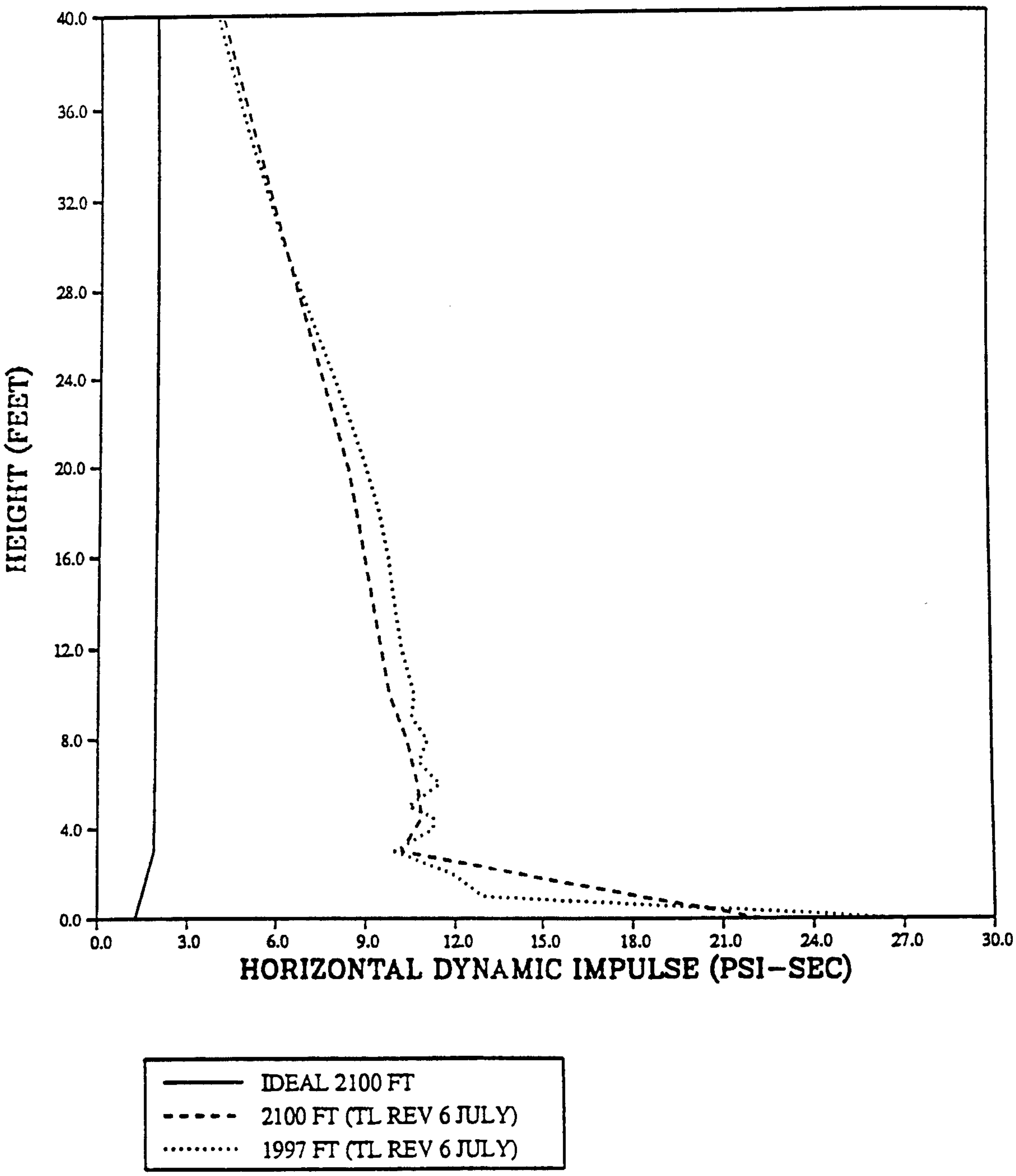
PRISCILLA DESERT
HORIZONTAL DYNAMIC PRESSURE PEAKS
VERTICAL PROFILE AT 4900 FEET



PRISCILLA DESERT
HORIZONTAL DYNAMIC PRESSURE PEAKS
VERTICAL PROFILE AT 5350 FEET



DESERT PRISCILLA
HORIZONTAL DYNAMIC PRESSURE IMPULSE
VERTICAL PROFILE AT 2100 FEET



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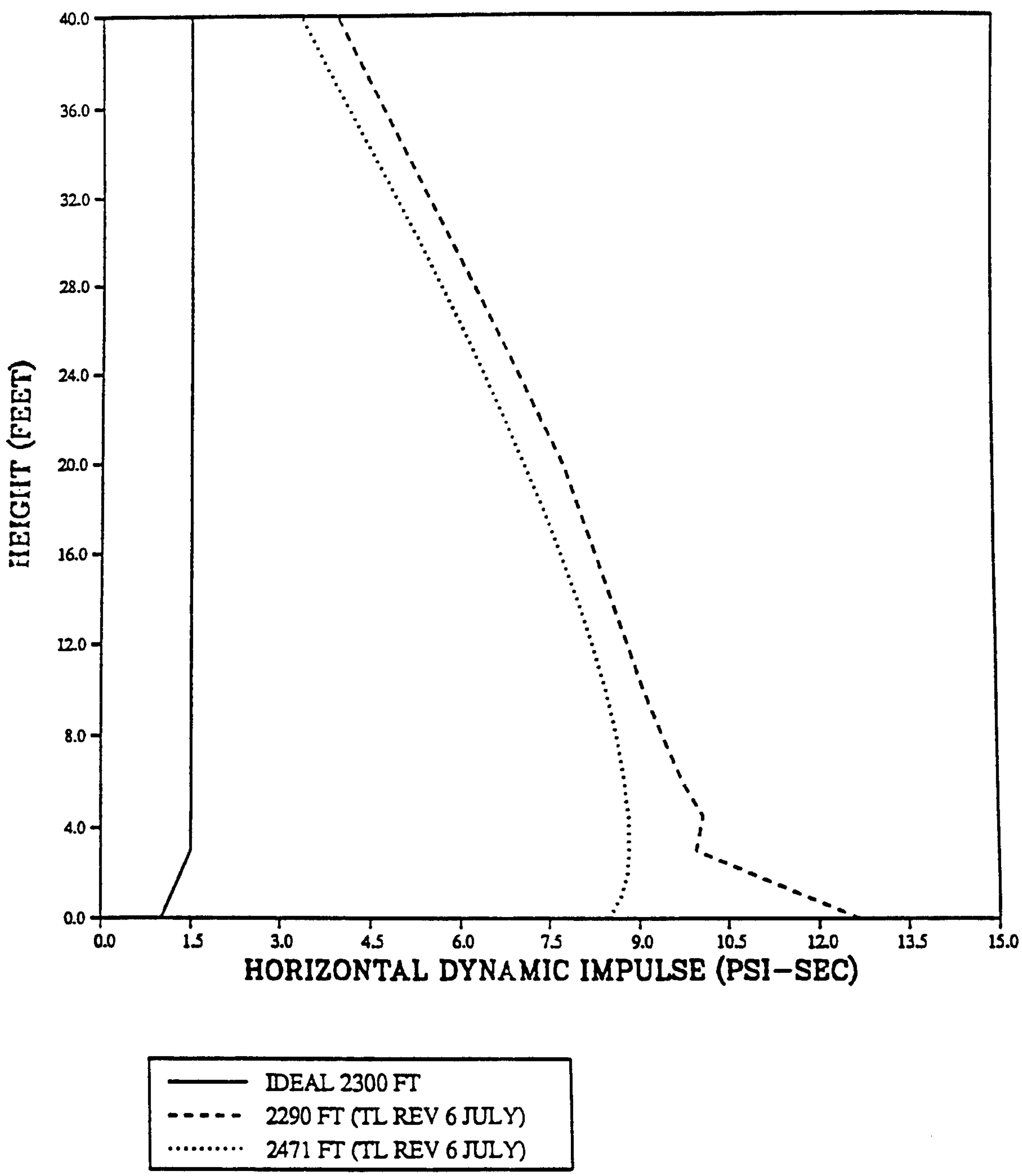
HORIZONTAL DYNAMIC PRESSURE IMPULSE
VERTICAL PROFILE AT 2300 FEET



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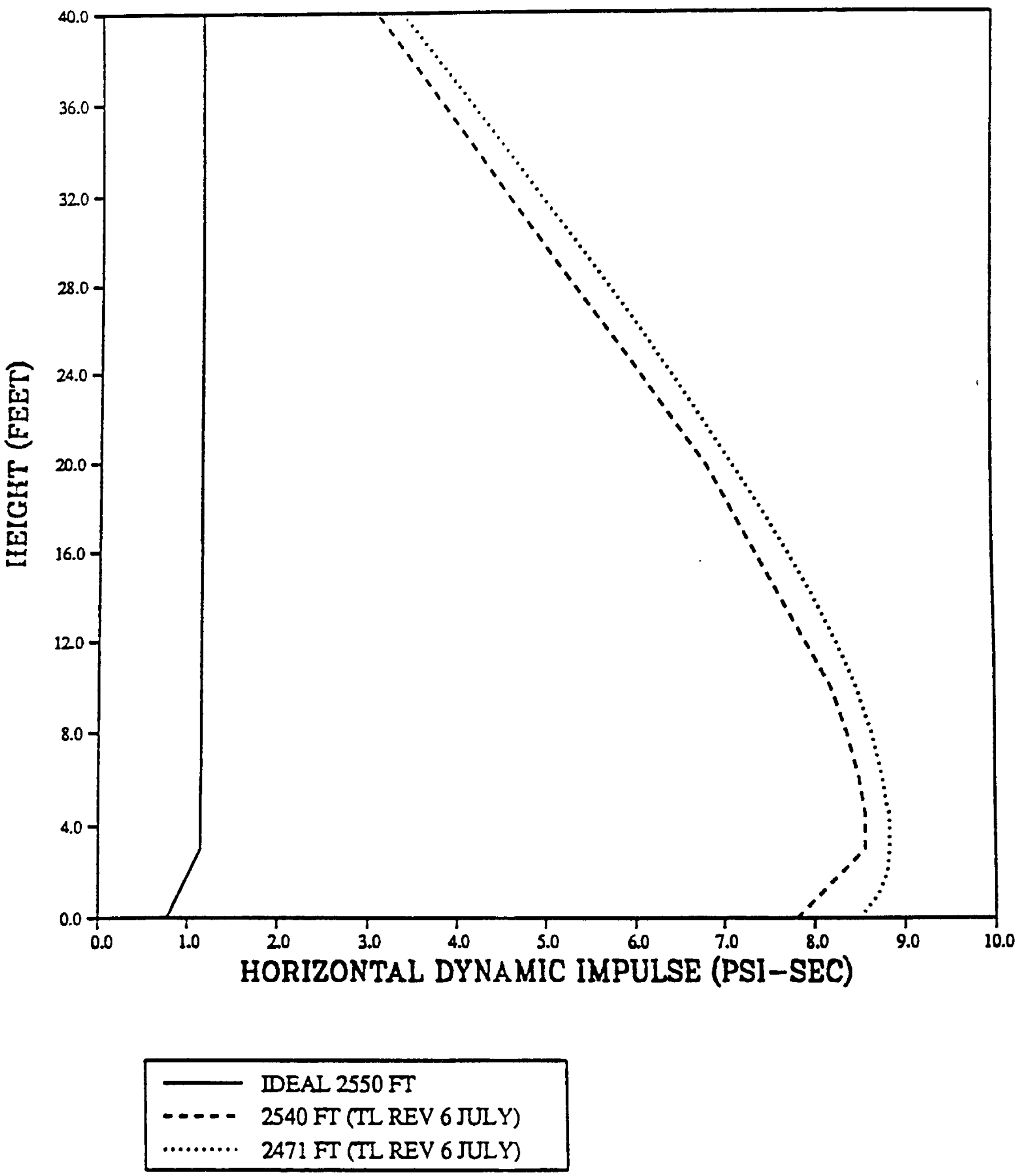
HORIZONTAL DYNAMIC PRESSURE IMPULSE
VERTICAL PROFILE AT 2550 FEET



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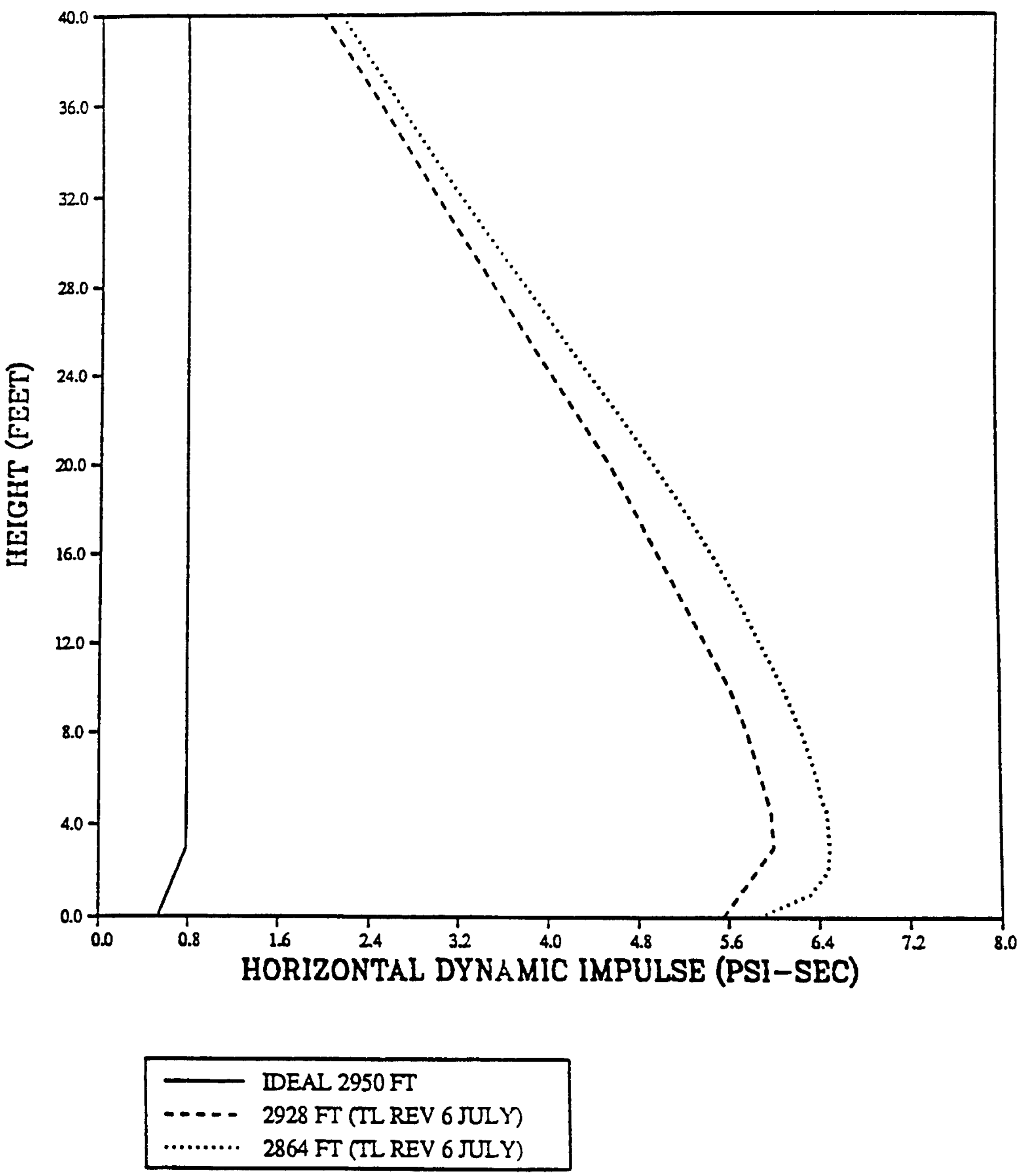
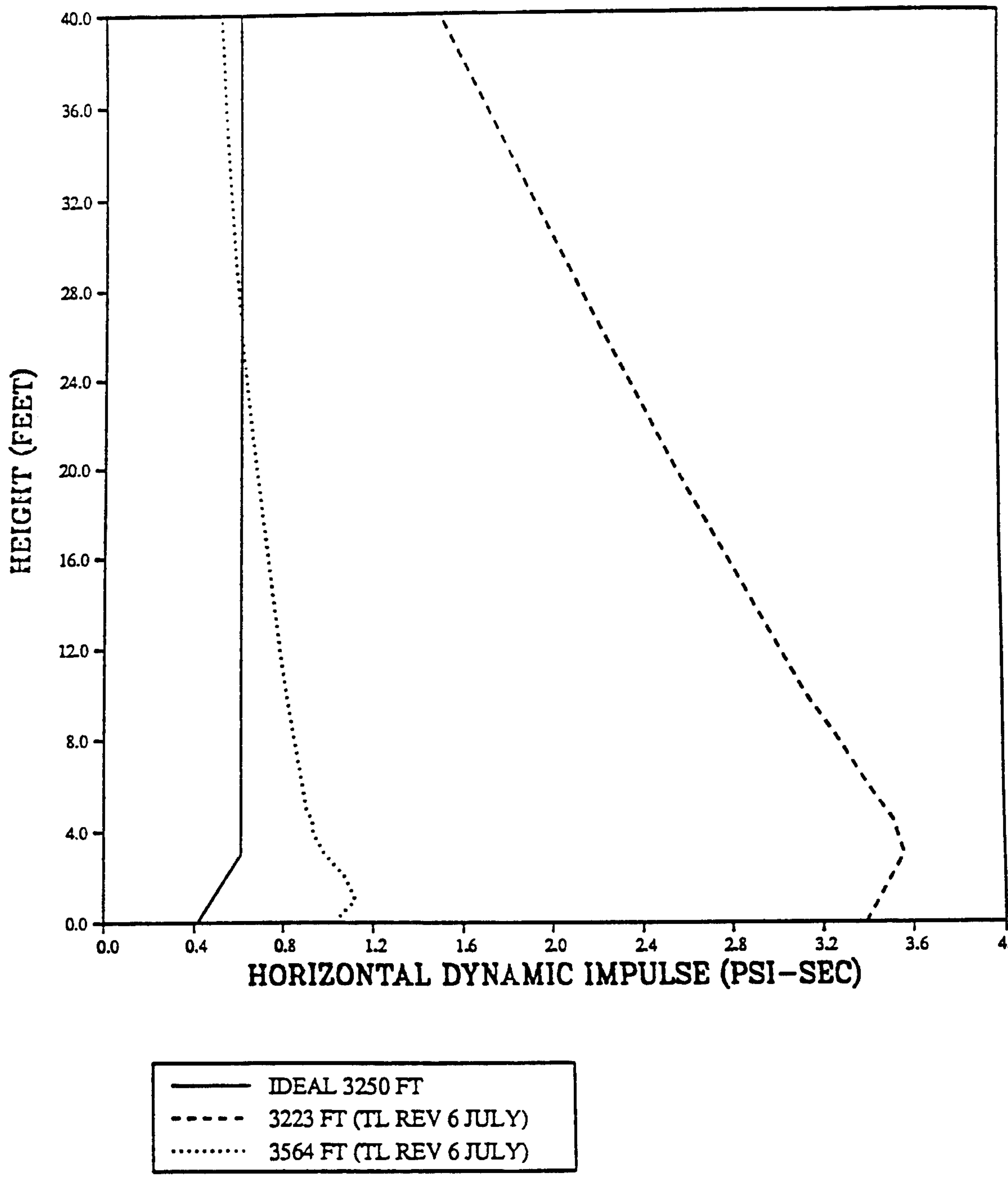
HORIZONTAL DYNAMIC PRESSURE IMPULSE
VERTICAL PROFILE AT 2950 FEET



DESERT PRISCILLA
HORIZONTAL DYNAMIC PRESSURE IMPULSE
VERTICAL PROFILE AT 3250 FEET



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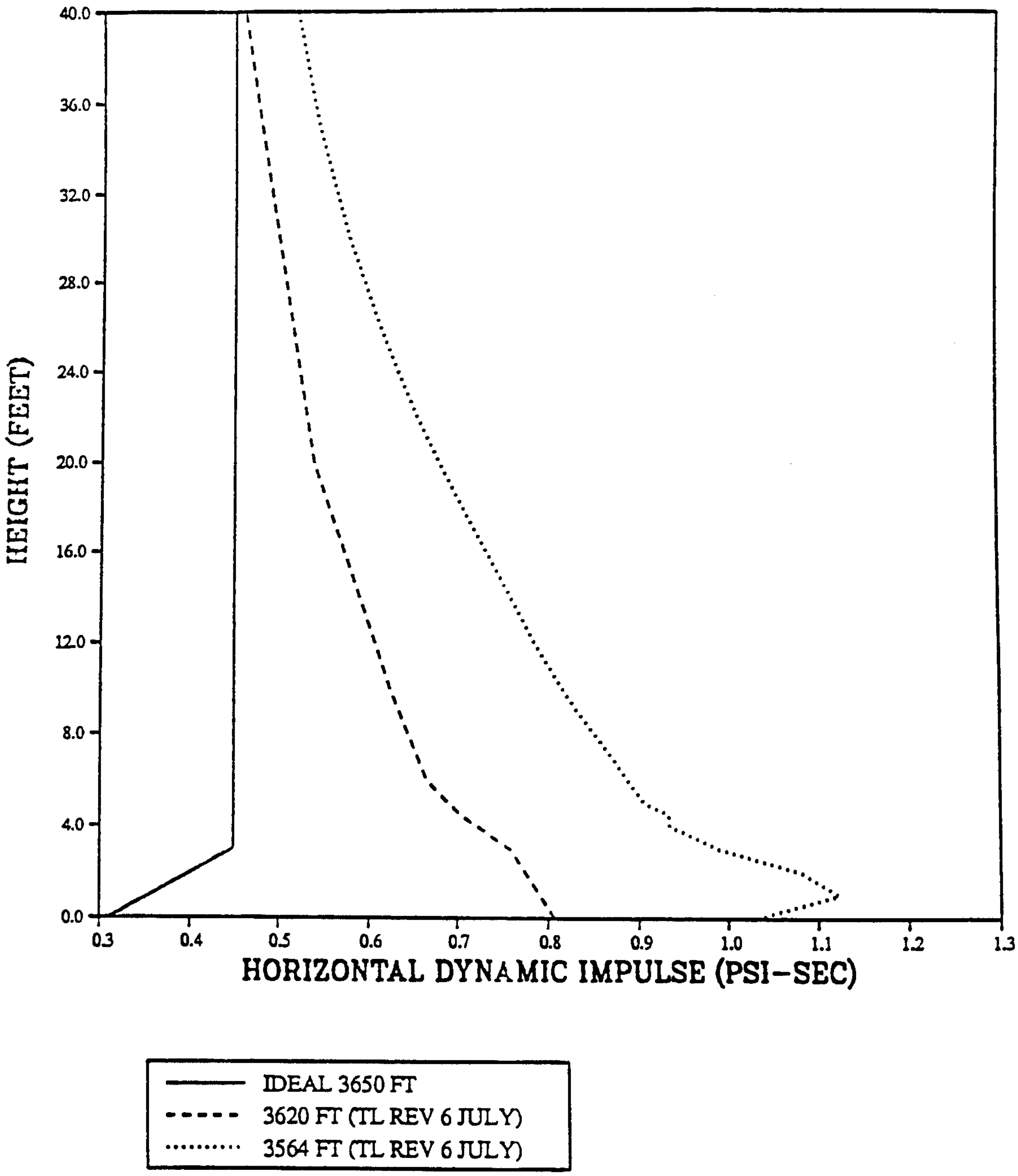
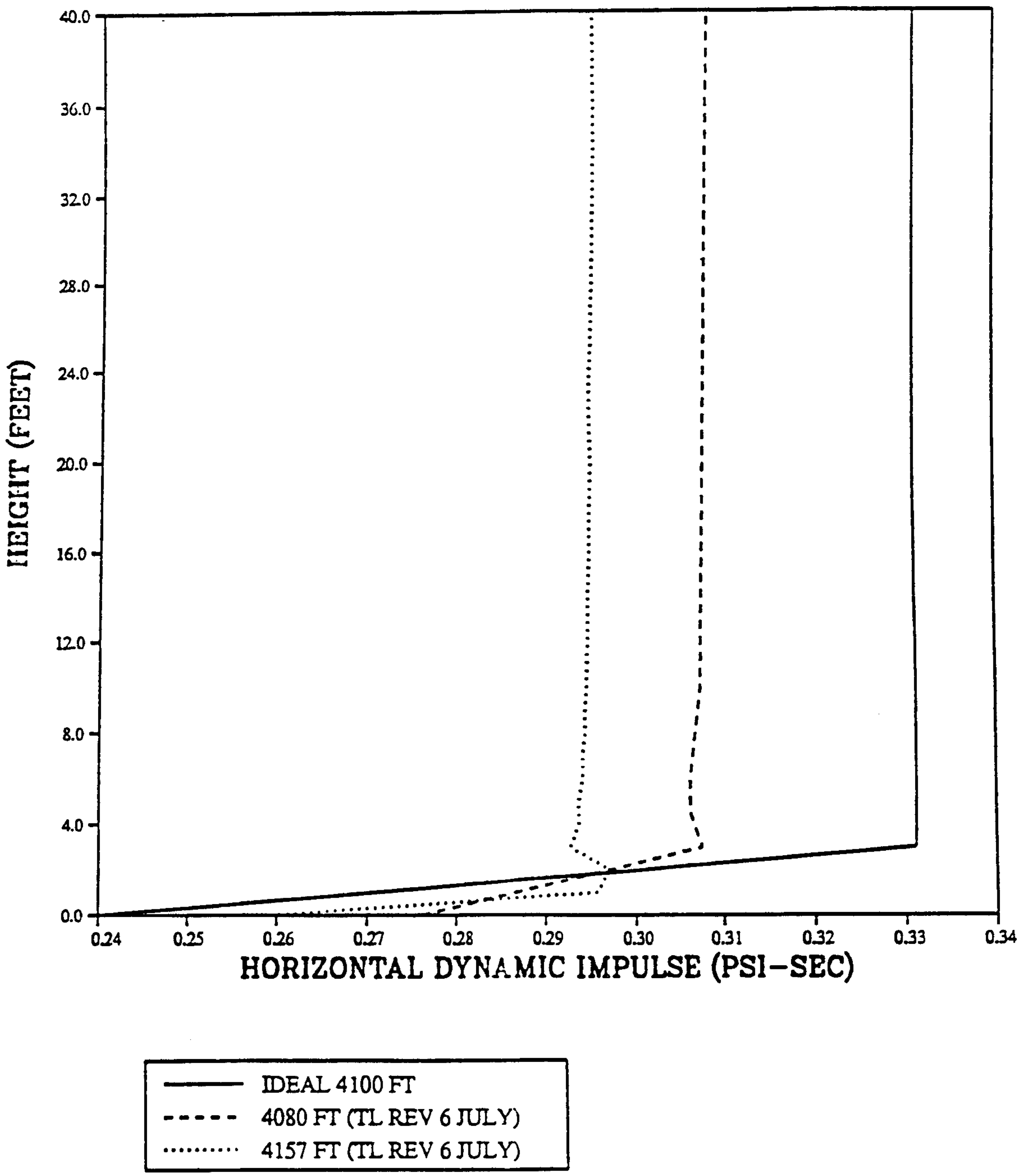
HORIZONTAL DYNAMIC PRESSURE IMPULSE
VERTICAL PROFILE AT 3650 FEET



DESERT PRISCILLA
HORIZONTAL DYNAMIC PRESSURE IMPULSE
VERTICAL PROFILE AT 4100 FEET



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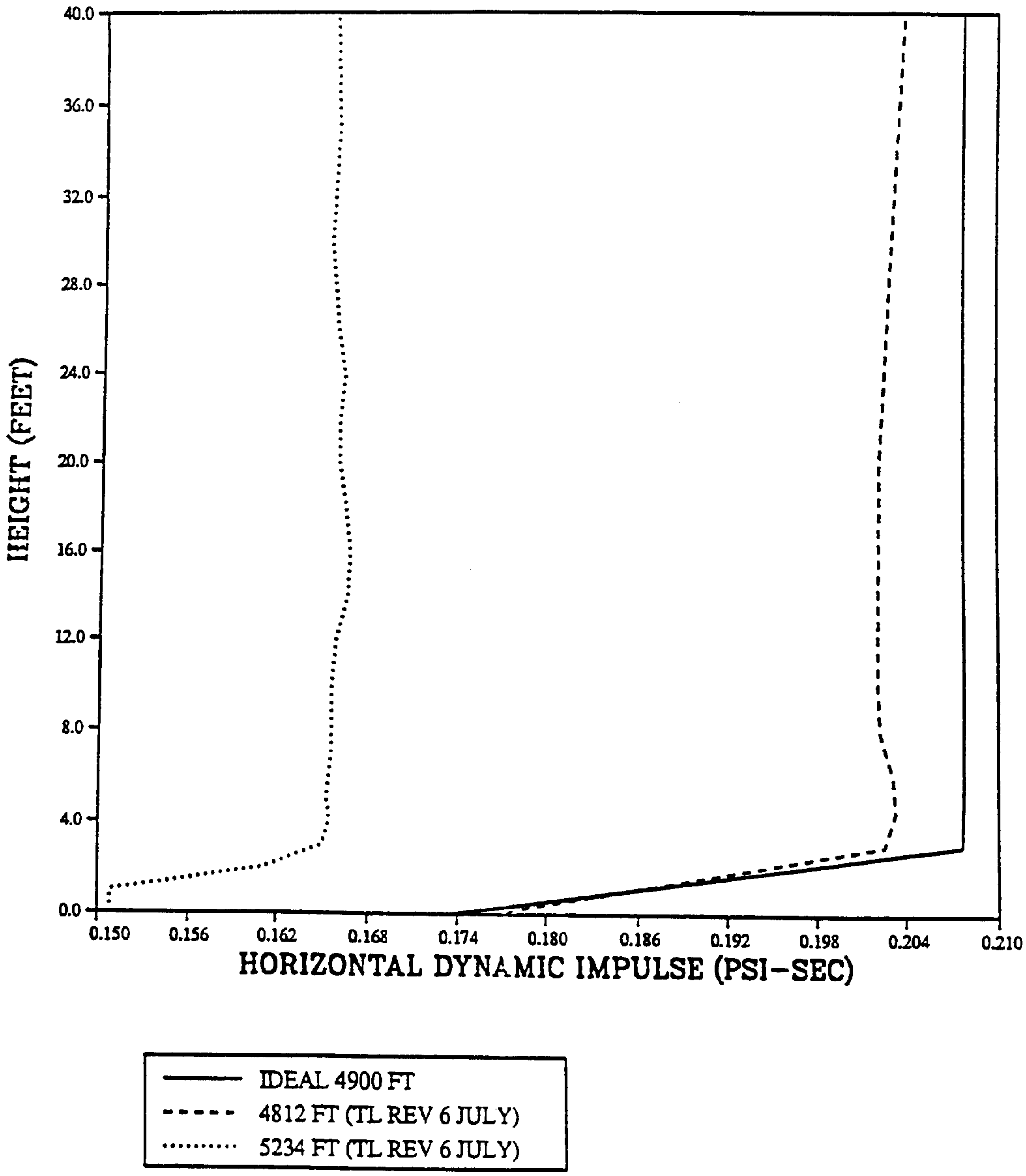
HORIZONTAL DYNAMIC PRESSURE IMPULSE
VERTICAL PROFILE AT 4900 FEET



BE 9:48 25AUG94

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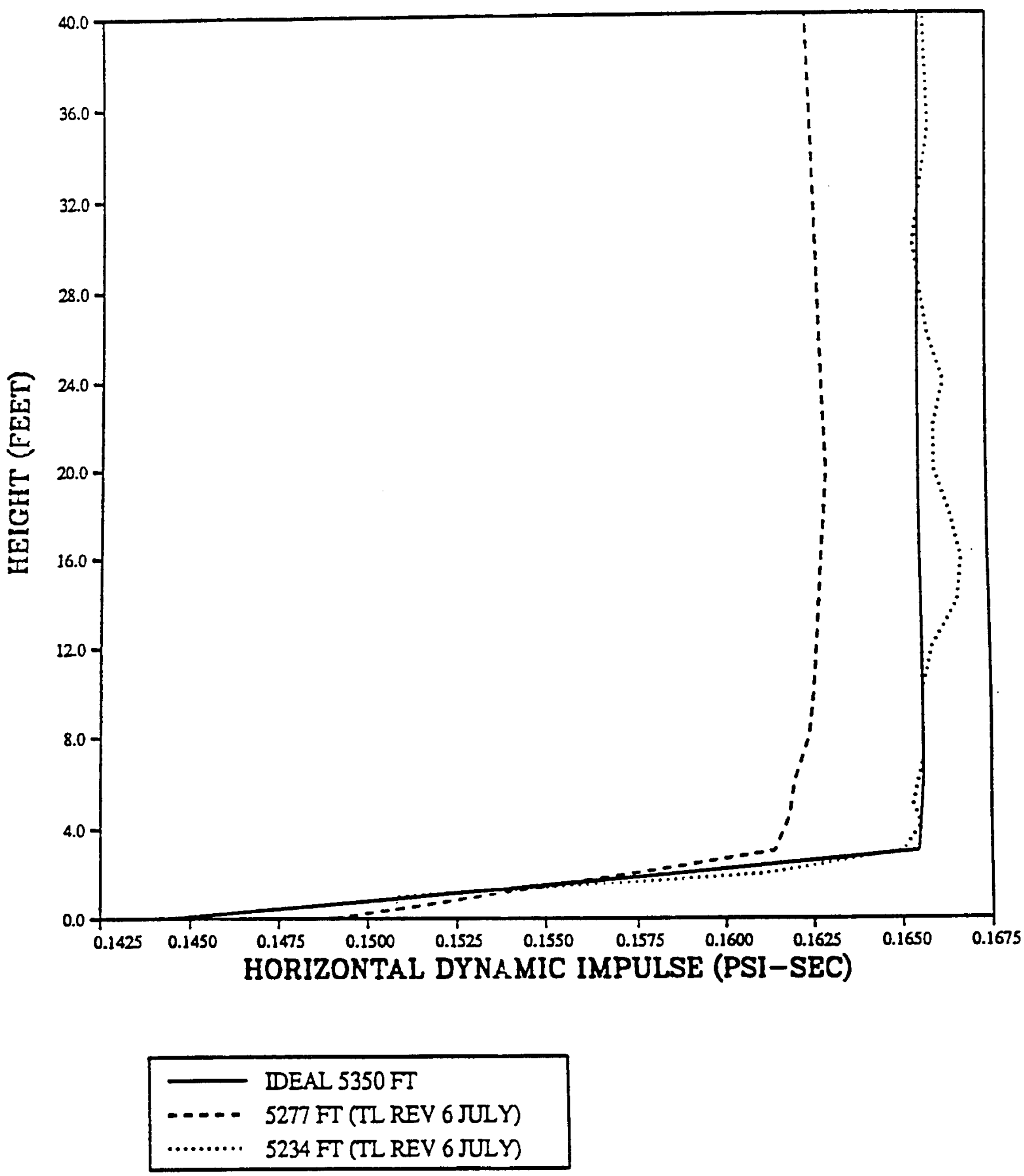
HORIZONTAL DYNAMIC PRESSURE IMPULSE
VERTICAL PROFILE AT 5350 FEET



APPENDIX D

CONVERSION TABLE

Conversion factors for U.S. Customary to metric (SI) units of measurement

MULTIPLY → BY → TO GET
TO GET ← BY ← DIVIDE

angstrom	1.000 000 X E -10	meters (m)
atmosphere (normal)	1.013 25 X E +2	kilo pascal (kPa)
bar	1.000 000 X E +2	kilo pascal (kPa)
barn	1.000 000 X E -28	meter ^{2} (m^2)
British thermal unit (thermochemical)	1.054 350 X E +3	joule (J)
calorie (thermochemical)	4.184 000	joule (J)
cal (thermochemical)/cm ^{2}	4.184 000 X E -2	mega joule/m ^{2} (MJ/m ^{2})
curie	3.700 000 X E +1	* giga becquerel (GBq)
degree (angle)	1.745 329 X E -2	radian (rad)
degree Fahrenheit	$t_K = (t^\circ f + 459.67)/1.8$	degree kelvin (K)
electron volt	1.602 19 X E -19	joule (J)
erg	1.000 000 X E -7	joule (J)
erg/second	1.000 000 X E -7	watt (W)
foot	3.048 000 X E -1	meter (m)
foot-pound-force	1.355 818	joule (J)
gallon (U.S. liquid)	3.785 412 X E -3	meter ^{3} (m^3)
inch	2.540 000 X E -2	meter (m)
jerk	1.000 000 X E +9	joule (J)
joule/kilogram (J/kg) (radiation dose absorbed)	1.000 000	Gray (Gy)
kilotons	4.183	terajoules
kip (1000 lbf)	4.448 222 X E +3	newton (N)
kip/inch ^{2} (ksi)	6.894 757 X E +3	kilo pascal (kPa)
ktap	1.000 000 X E +2	newton-second/m ^{2} (N-s/m ^{2})
micron	1.000 000 X E -6	meter (m)
mil	2.540 000 X E -5	meter (m)
mile (international)	1.609 344 X E +3	meter (m)
ounce	2.834 952 X E -2	kilogram (kg)
pound-force (lbs avoirdupois)	4.448 222	newton (N)
pound-force inch	1.129 848 X E -1	newton-meter (N•m)
pound-force/inch	1.751 268 X E +2	newton/meter (N/m)
pound-force/foot ^{2}	4.788 026 X E -2	kilo pascal (kPa)
pound-force/inch ^{2} (psi)	6.894 757	kilo pascal (kPa)
pound-mass (lbm avoirdupois)	4.535 924 X E -1	kilogram (kg)
pound-mass-foot ^{2} (moment of intertia)	4.214 011 X E -2	kilogram-meter ^{2} (kg•m ^{2})
pound-mass/foot ^{3}	1.601 846 X E +1	kilogram/meter ^{3} (kg/m ^{3})
rad (radiation dose absorbed)	1.000 000 X E -2	** Gray (Gy)
roentgen	2.579 760 X E -4	coulomb/kilogram (C/kg)
shake	1.000 000 X E -8	second (s)
slug	1.459 390 X E +1	kilogram (kg)
torr (mm HG, O°C)	1.333 22 X E -1	kilo pascal (kPa)

* The becquerel (Bq) is the SI unit of radioactivity; 1 Bq = 1 event/s.
** The Gray (GY) is the SI unit of absorbed radiation.

A more complete listing of conversions may be found in "Metric Practice Guide E 380-74," American Society for Testing and Materials.

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